

# Observational, Radiative and Dynamical Implications of Scale Invariance Near the Tropical Tropopause

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# Scaling Exponent $H_1$

- Start with signal  $f(t)$ .
- The first order structure function associated with  $f$  is

$$S_1(r; f) = \langle |f(t+r) - f(t)| \rangle$$

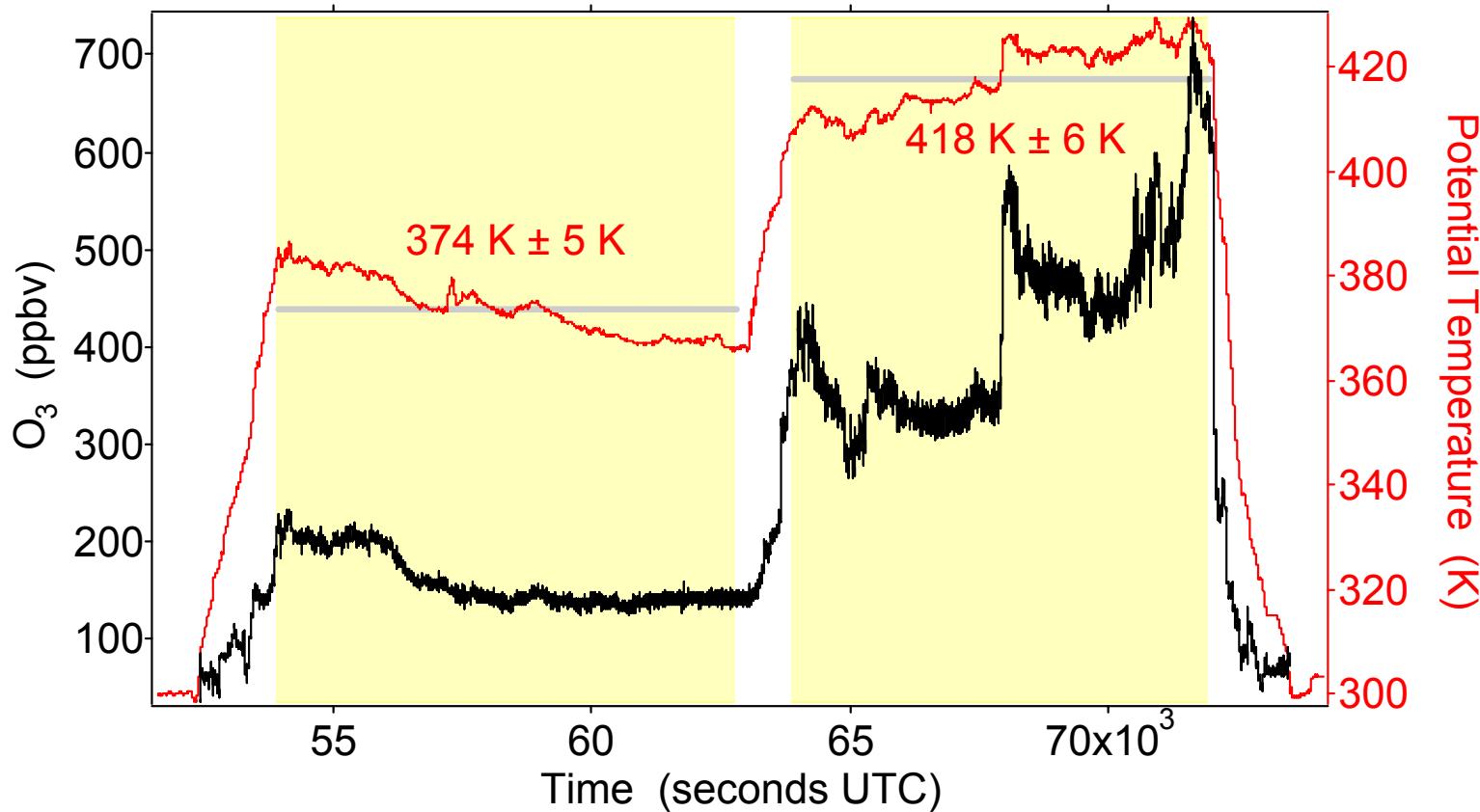
where the independent variable  $r$  is called the “lag”.

- Plot  $\log(S_1)$  vs.  $\log(r)$ . If the points describe a relatively straight line, then  $f$  scales, and  $H_1$  is given by the slope of the line.
- $H_1$  ranges from 0 to 1.
  - Values near 1: “persistence”, positive neighbor-to-neighbor correlation.
  - Values near 0: “anti-persistence”, negative neighbor-to-neighbor correlation.

# $H_1$ for Air Along Aircraft Flight Tracks

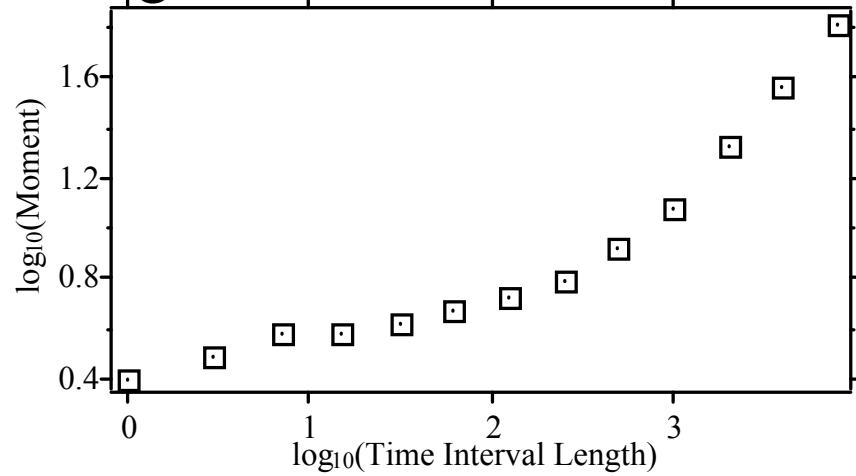
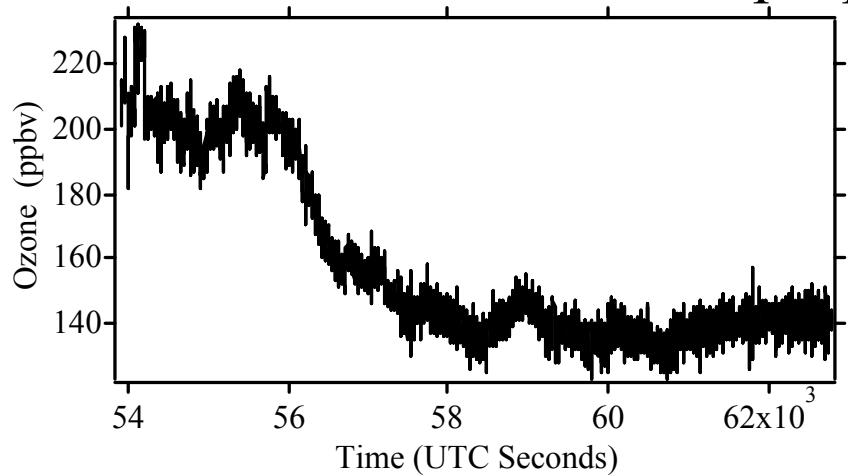
- $H_1$  is related to spectral exponent  $\beta$  by  $\beta = 2H_1 + 1$ .
- Kolmogorov theory predicts  $\beta = 5/3$  for the atmosphere in the horizontal direction, corresponding to  $H_h = 1/3$ .
- Bolgiano's arguments predict  $\beta = 11/5$  in the vertical direction, corresponding to  $H_v = 3/5$ .
- Even in “level” flight, an aircraft samples a mix of the horizontal and vertical structure of the atmosphere.
- The scaling exponent along an aircraft flight track is given by  $H_z = H_h/H_v = 5/9 \approx 0.56$ .
- Empirically, we see a slightly lower value, possibly due to the inertia of the aircraft. (Under investigation.)

# WAM 19980511 WB57

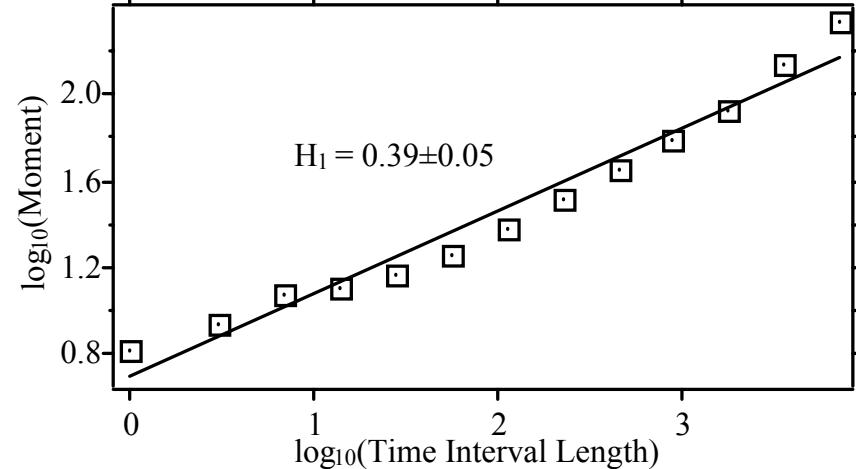
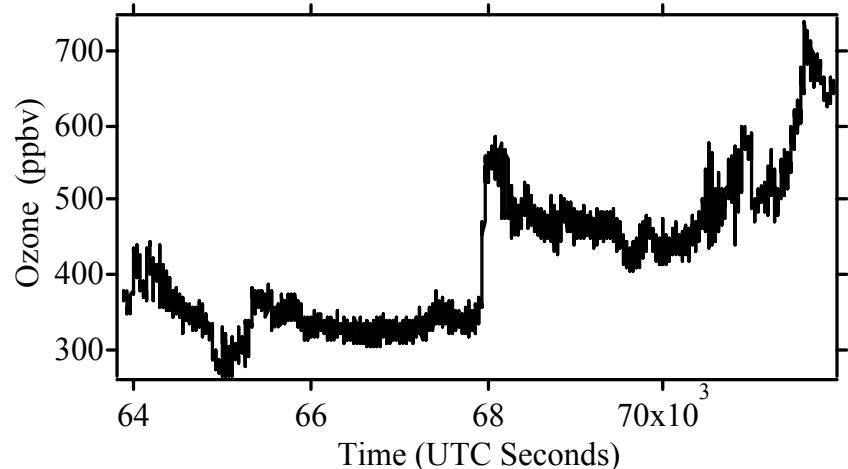


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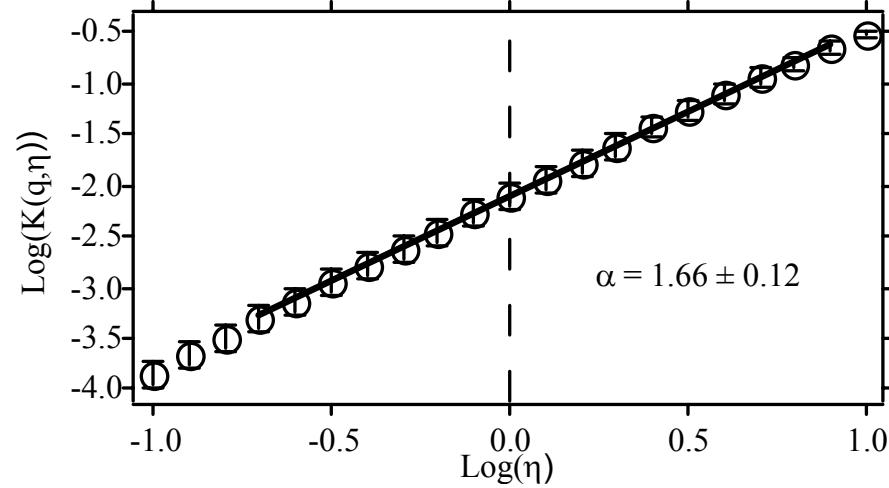
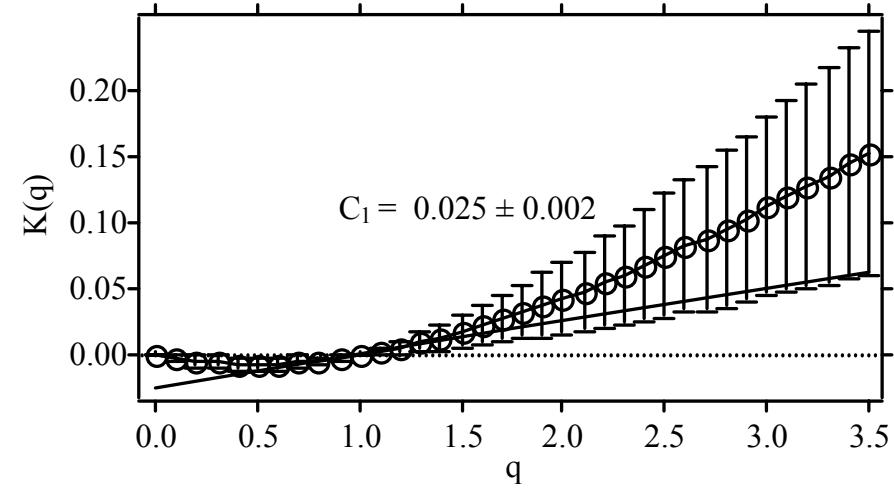
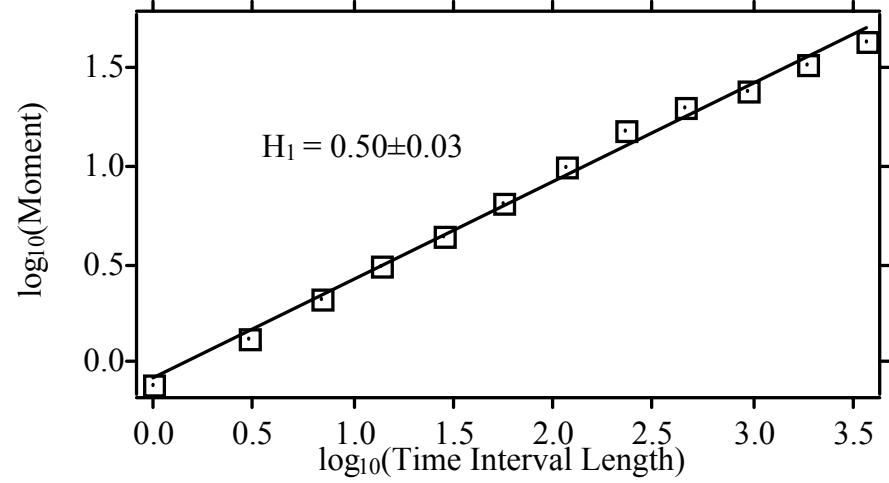
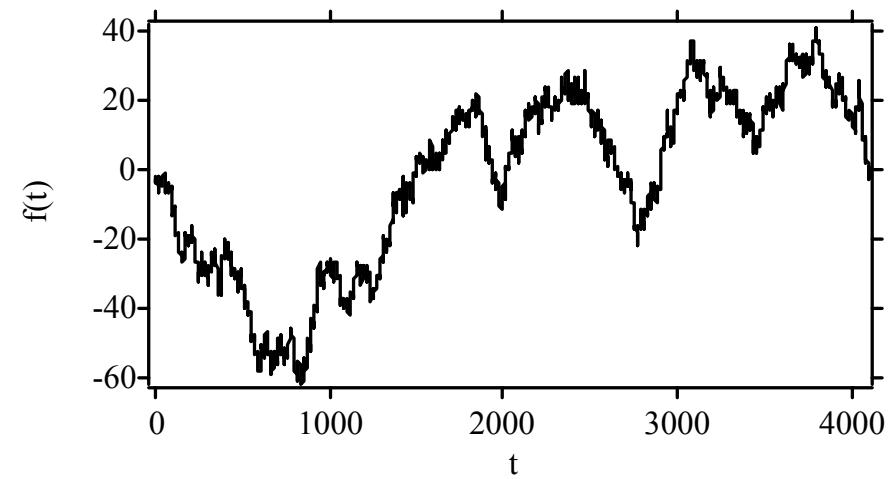
## Tropospheric Segment



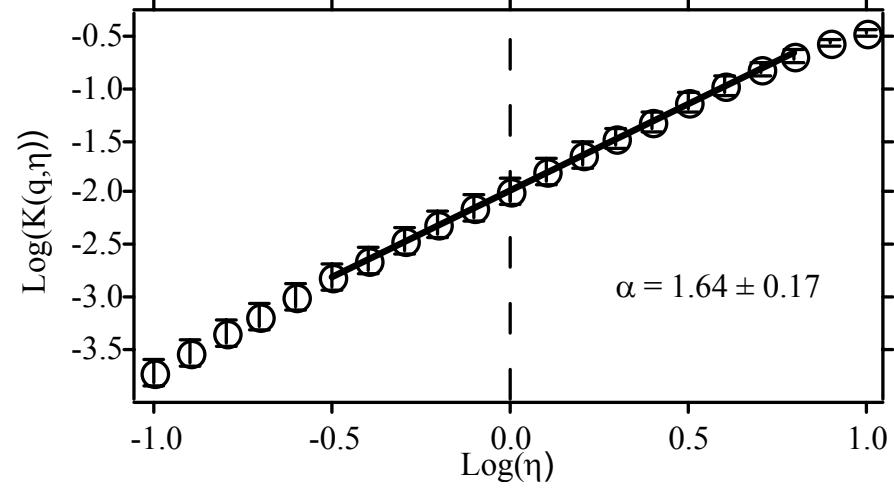
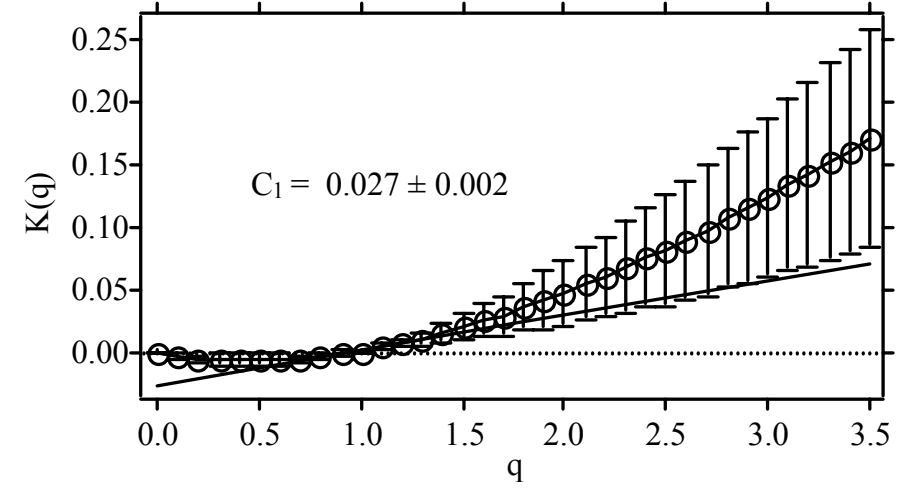
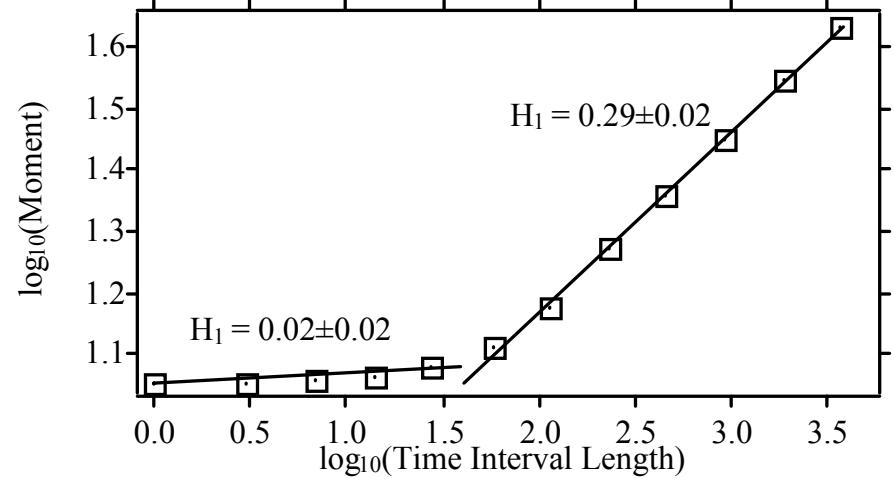
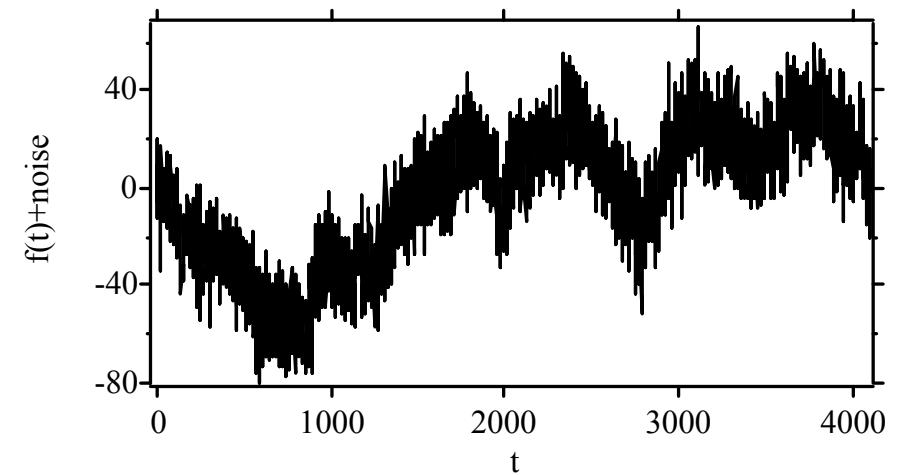
## Stratospheric Segment



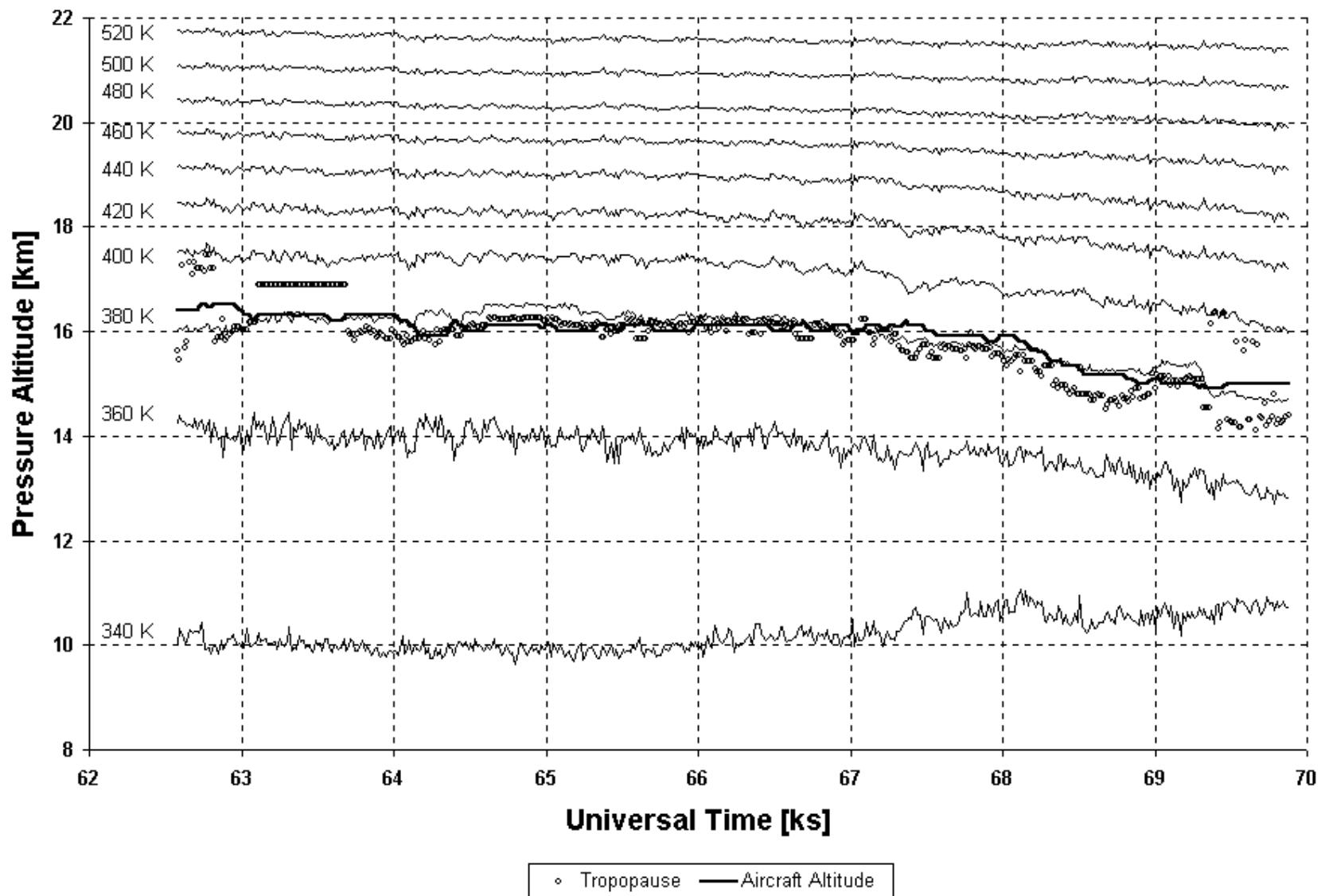
# Synthetic Signal



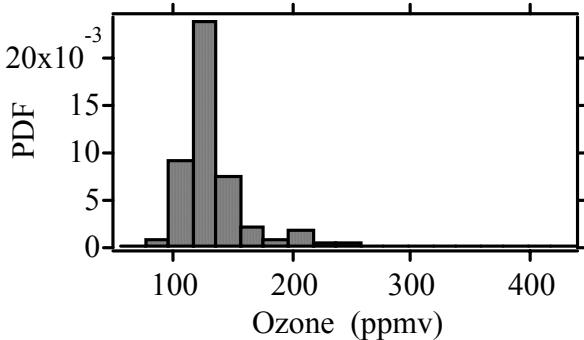
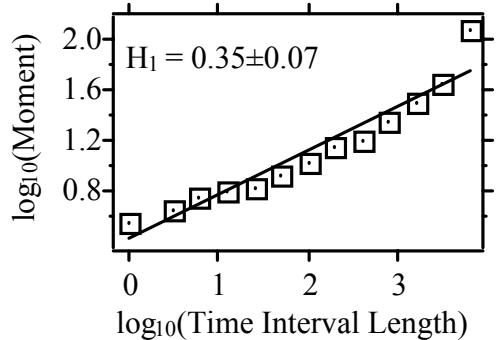
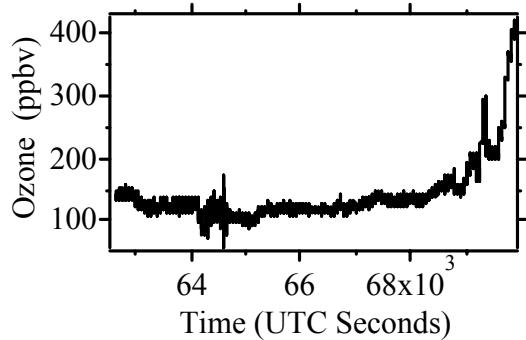
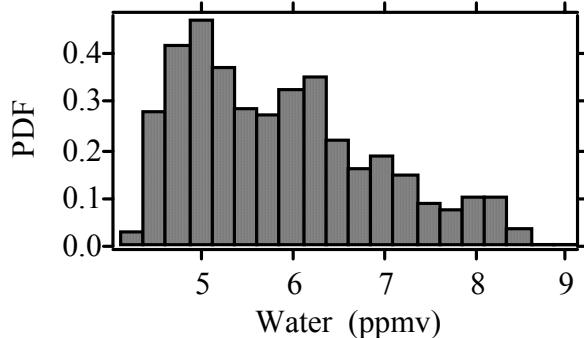
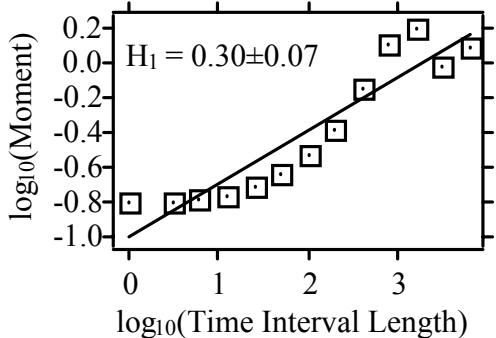
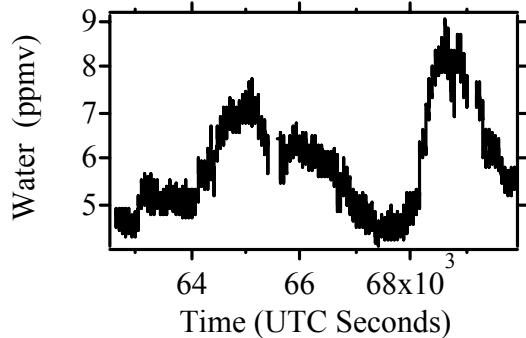
# Synthetic Signal Plus 10% Gaussian Noise



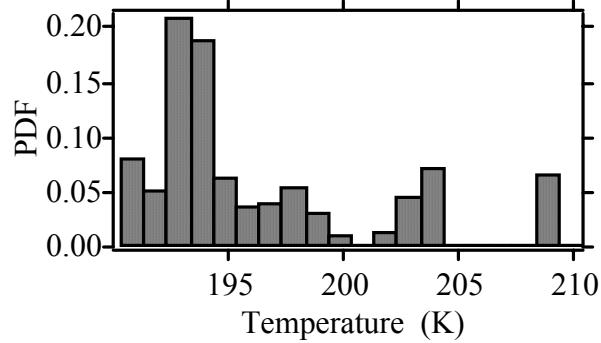
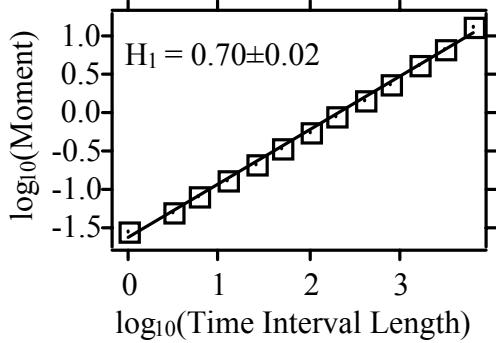
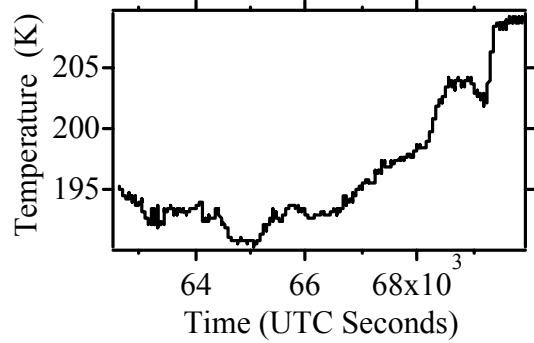
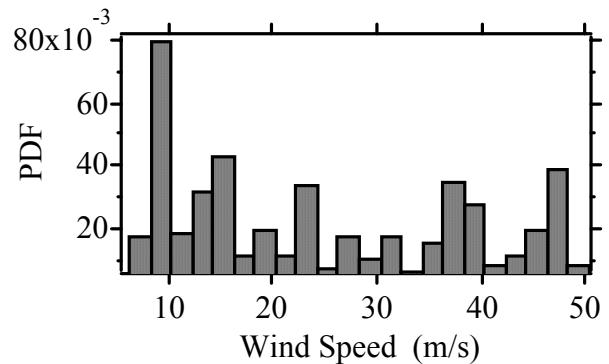
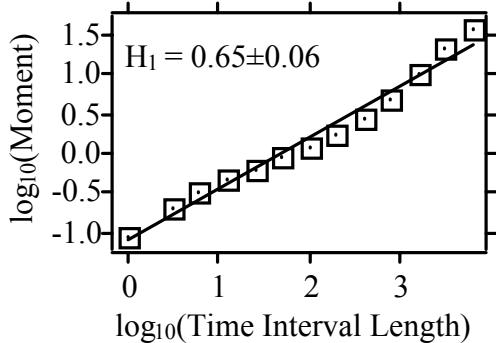
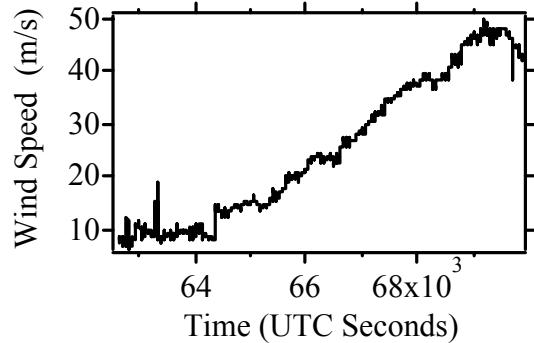
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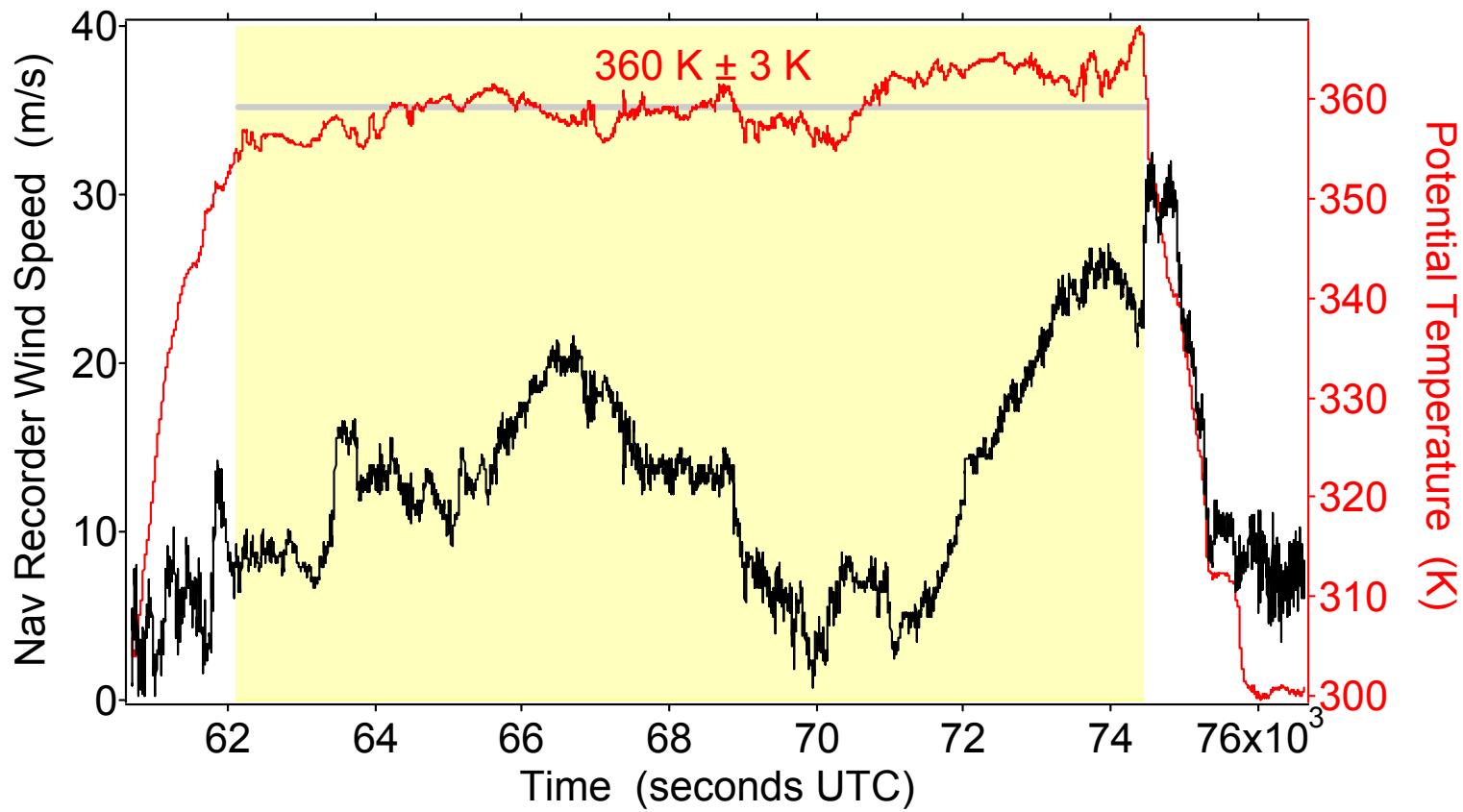
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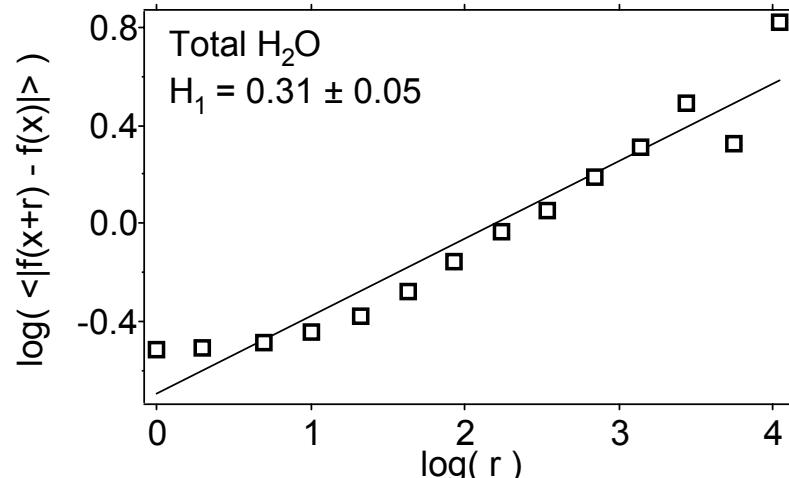
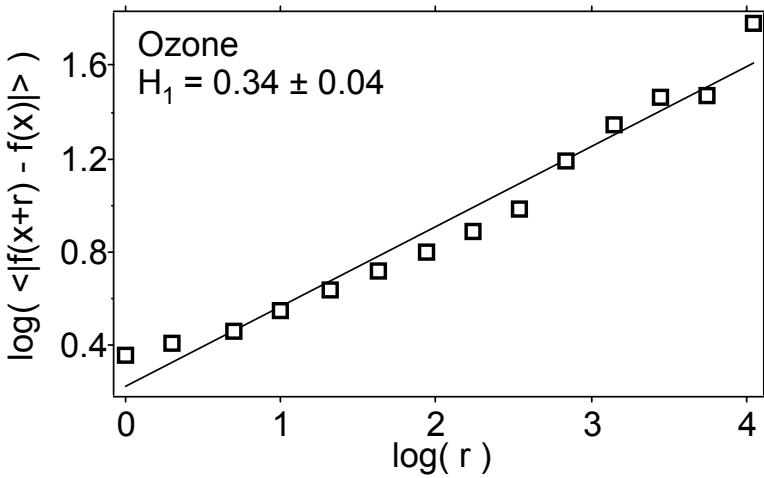
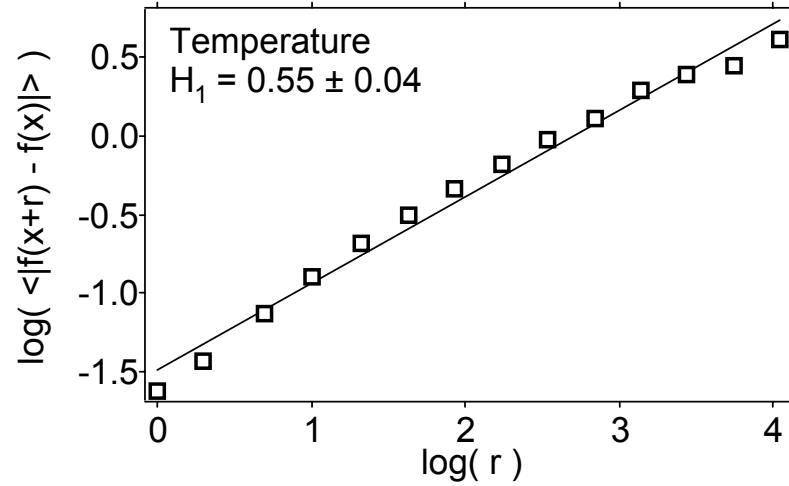
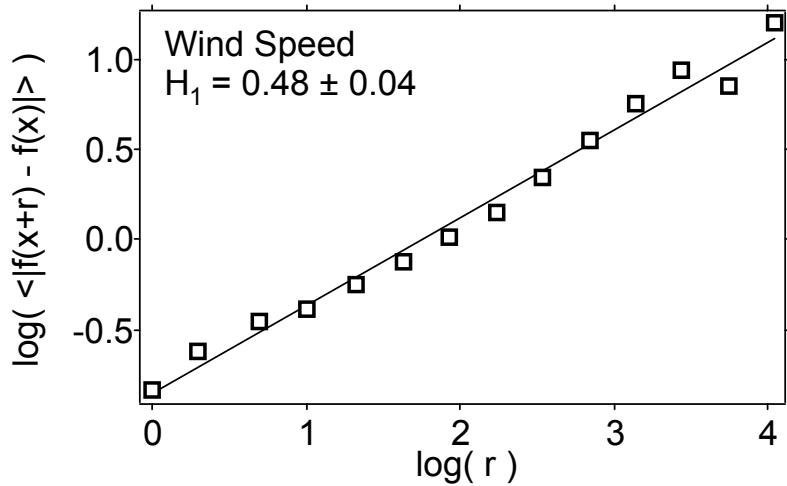
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# ACCENT 19990921 WB57



# 19990921 Scaling Exponents



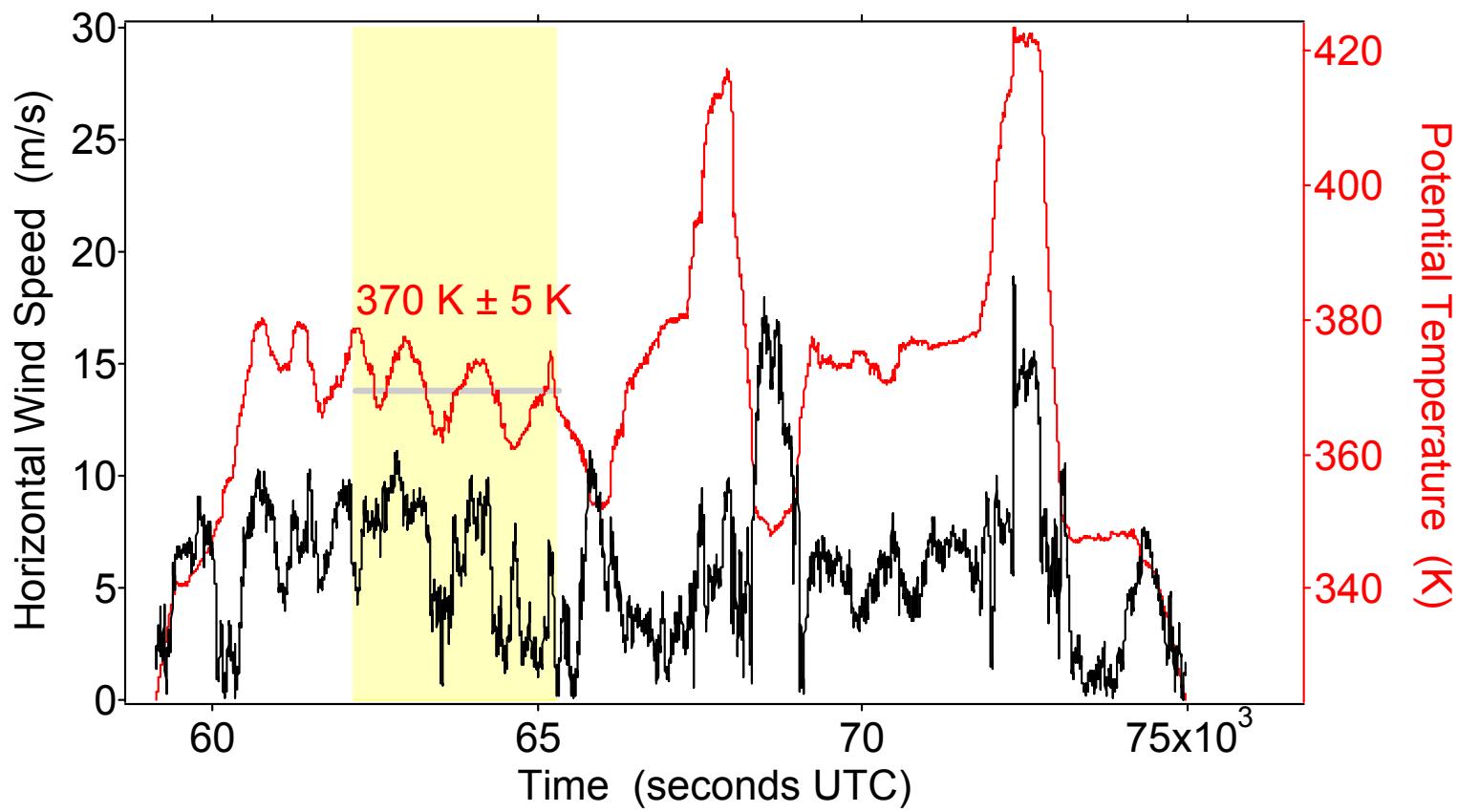
# Flight Segments Included In Analysis

Aircraft	Date yyyymmdd	Segment duration (s)	Coordinates (°lat, °lon)	Segment center time (UTCs)	Approximate mean θ (K)
ER-2	19870203	6971	(14°S, 129°E) (18°S, 117°E)	91635	412
ER-2	19870814	6845	(7°N, 79°W) (5°S, 78°W)	48470	391
ER-2	19941026	8207	(15°N, 158°W) (1°N, 159°W)	76878	410
WB57F	19980409	7017	(28°N, 93°W) (17°N, 84°W)	59534	368
WB57F	19980409	5943	(19°N, 85°W) (27°N, 91°W)	66911	413
WB57F	19980501	8209	(28°N, 94°W) (14°N, 95°W)	57962	362
WB57F	19980501	7242	(13°N, 95°W) (26°N, 95°W)	66259	370
WB57F	19980504	7926	(14°N, 95°W) (28°N, 95°W)	68442	420
WB57F	19980507	5144	(30°N, 93°W) (33°N, 83°W)	56910	373
WB57F	19980511	8872	(28°N, 95°W) (11°N, 95°W)	58357	374
WB57F	19980511	8052	(13°N, 95°W) (28°N, 95°W)	67906	418
WB57F	19990920	13525	(28°N, 87°W) (5°N, 94°W)	46669	362
WB57F	19990921	10992	(13°N, 82°W) (28°N, 94°W)	68936	360
WB57F	20020726	3125	(22°N, 86°W) (17°N, 84°W)	63738	369

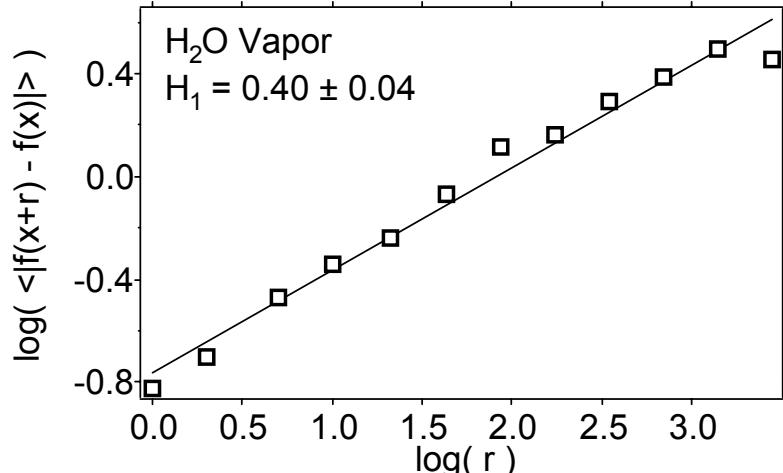
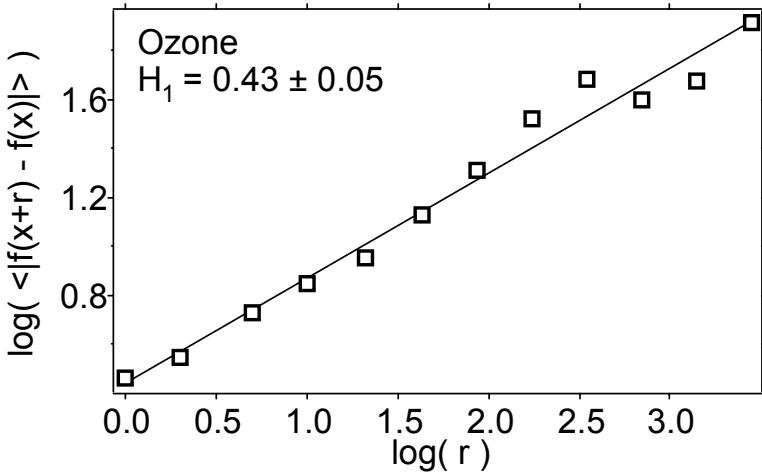
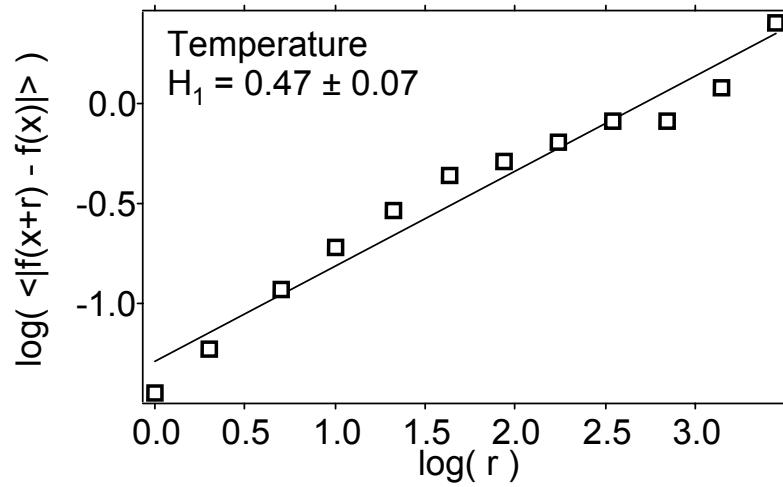
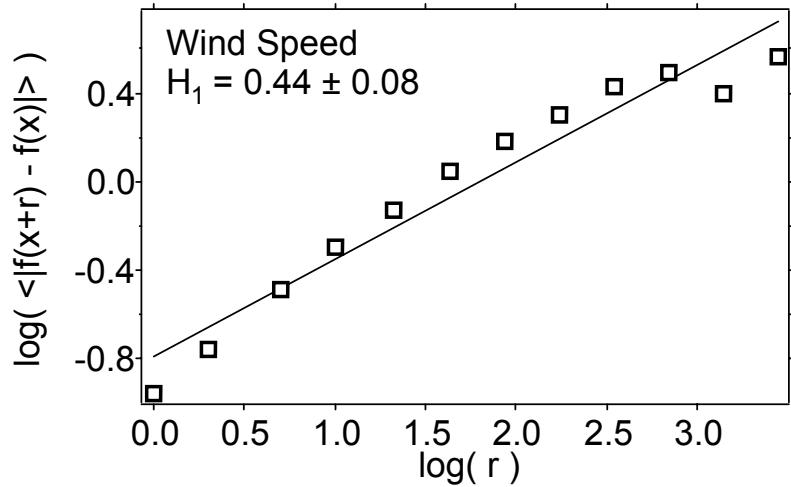
# Calculations of H<sub>1</sub>

Segment duration(s)	H <sub>1</sub> (H <sub>2</sub> O)	H <sub>1</sub> (O <sub>3</sub> )	H <sub>1</sub> ([u <sup>2</sup> +v <sup>2</sup> ] <sup>1/2</sup> )	H <sub>1</sub> (T)
6971	-	0.34 ± 0.07	-	0.49 ± 0.03
6845	-	-	0.35 ± 0.04	0.34 ± 0.04
8207	-	0.37 ± 0.04	0.49 ± 0.07	0.52 ± 0.02
7017	-	-	0.56 ± 0.07	0.66 ± 0.02
5943	-	0.43 ± 0.05	0.36 ± 0.04	0.61 ± 0.03
8209	0.43 ± 0.05	0.51 ± 0.08	0.64 ± 0.06	0.65 ± 0.04
7242	0.30 ± 0.07	0.35 ± 0.07	0.65 ± 0.06	0.70 ± 0.02
7926	-	0.48 ± 0.10	0.36 ± 0.05	0.59 ± 0.03
5144	0.35 ± 0.05	0.51 ± 0.09	0.56 ± 0.03	-
8872	-	-	0.57 ± 0.06	0.65 ± 0.04
8052	-	0.39 ± 0.05	0.43 ± 0.04	0.62 ± 0.03
13525	0.26 ± 0.04	0.37 ± 0.06	-	0.47 ± 0.09
10992	0.31 ± 0.04	0.33 ± 0.04	0.48 ± 0.04	0.55 ± 0.04
3125	0.40 ± 0.04	0.43 ± 0.05	0.44 ± 0.08	0.47 ± 0.07
Mean	0.34 ± 0.06	0.41 ± 0.07	0.49 ± 0.11	0.56 ± 0.10

# CRYSTAL-FACE 20020726 WB57



# 20020726 Scaling Exponents



# Summary

- Wind speed and temperature scale with  $H_1 = 5/9$ .
- Scale breaks for ozone and water on some flights at about 20 km appear to be instrumental.
- Total water, water vapor and ozone scale in the upper troposphere, as does carbon dioxide in the lower stratosphere, but not as passive scalars, i.e.  $H_1 \neq 5/9$ . Sources and sinks are operating faster than mixing.

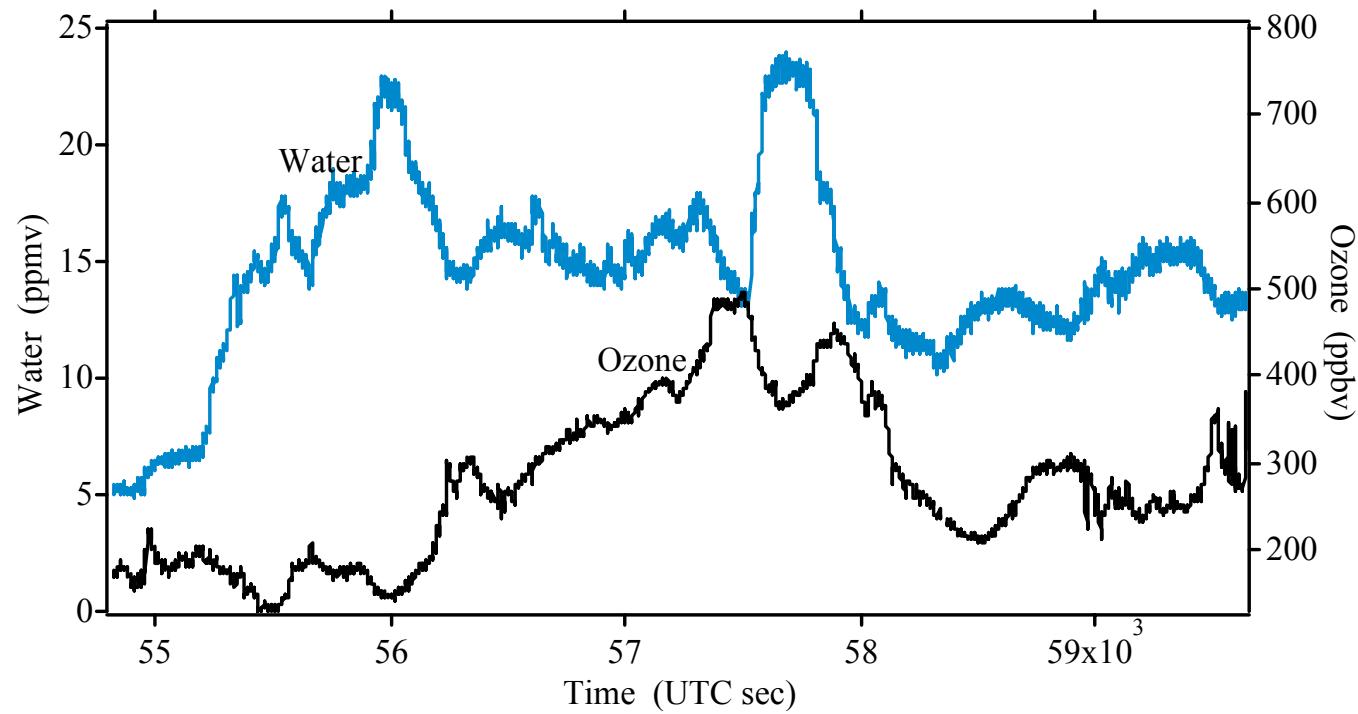
# Consequence

- Because the radiatively absorbing and emitting species scale, so must the energy input and output to the atmosphere: all scales play a role in forcing and dissipation.

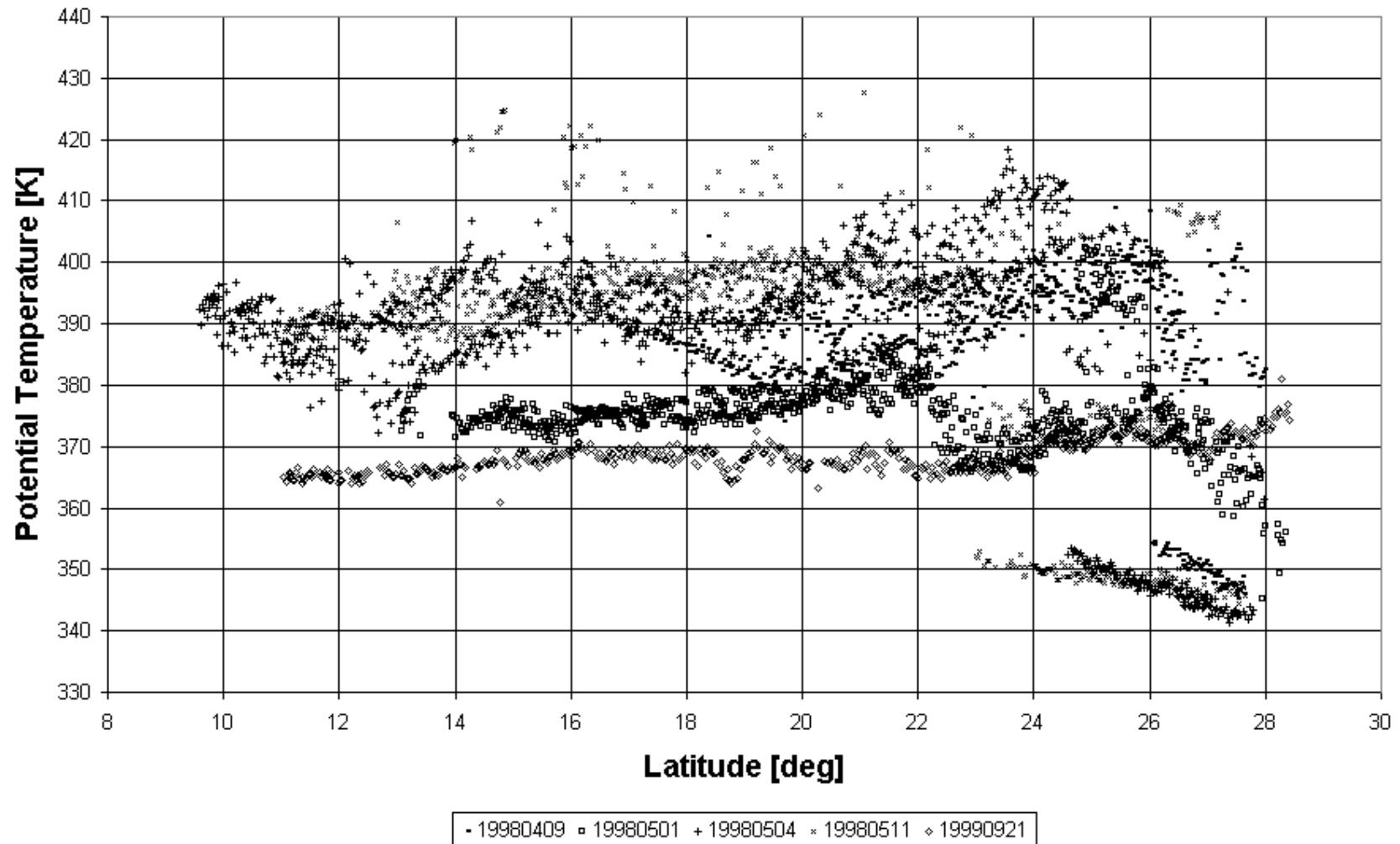
# Conclusions

- Better signal-to-noise ratio is required at high frequencies.
- Many more long, “constant level” flight tracks are needed in the troposphere, preferably with 10 Hz data.

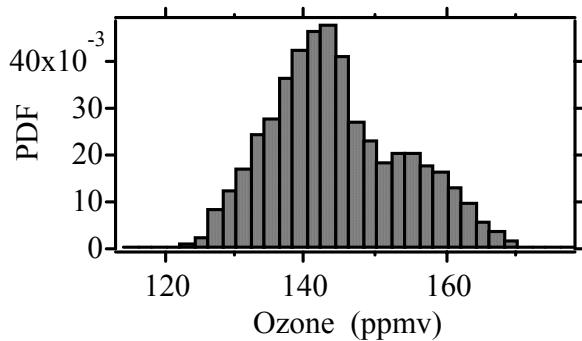
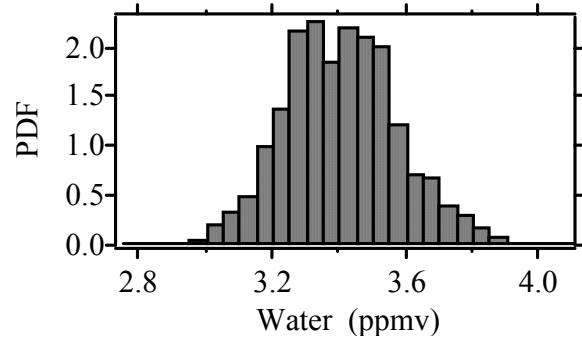
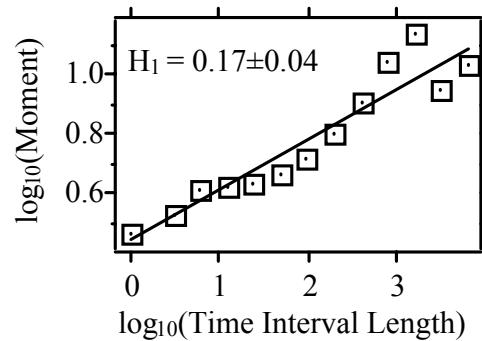
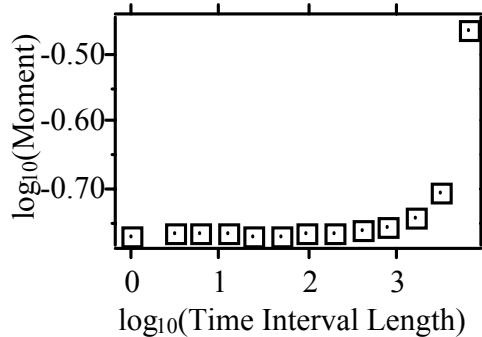
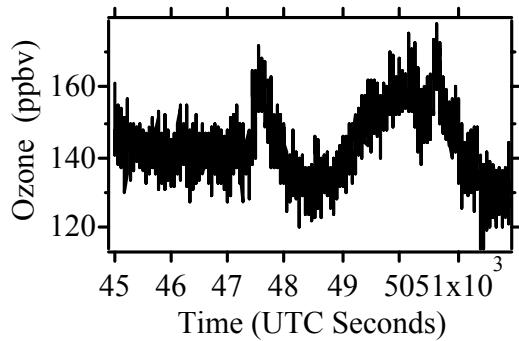
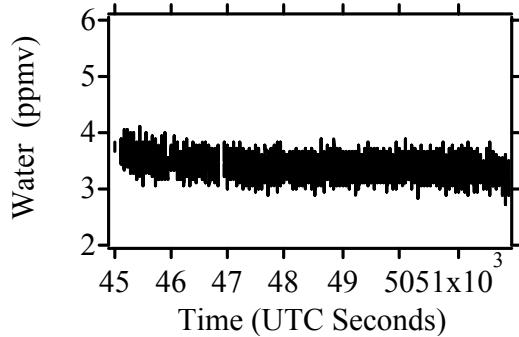
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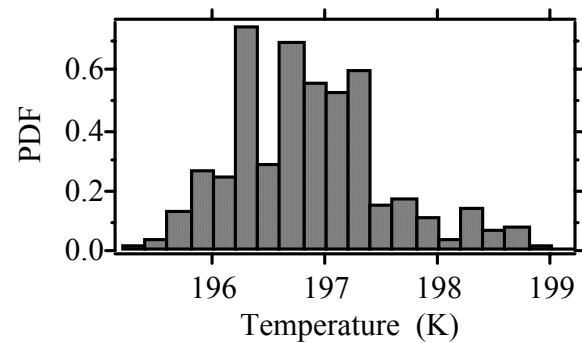
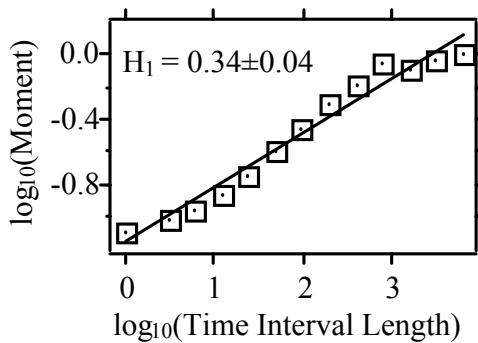
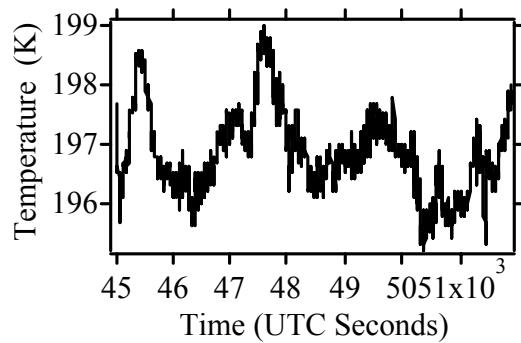
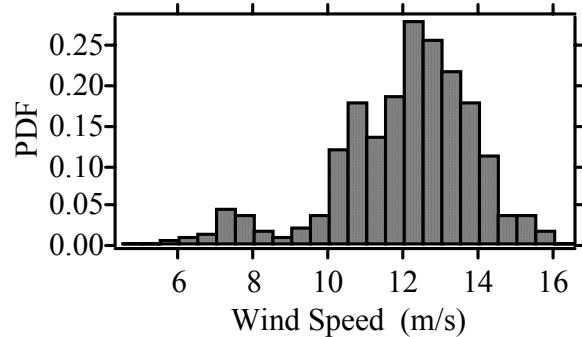
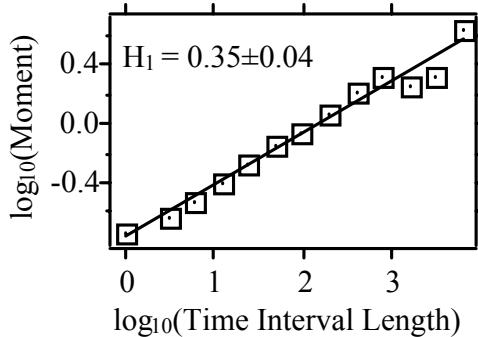
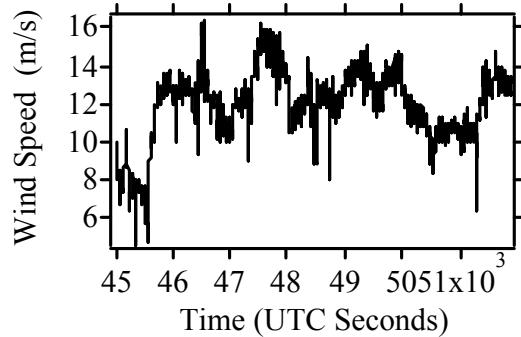
# Tropopause Potential Temperature vs. Latitude



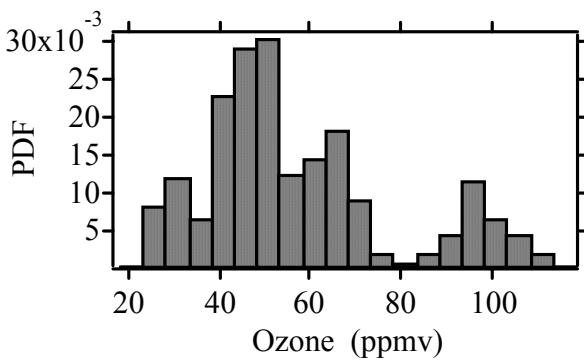
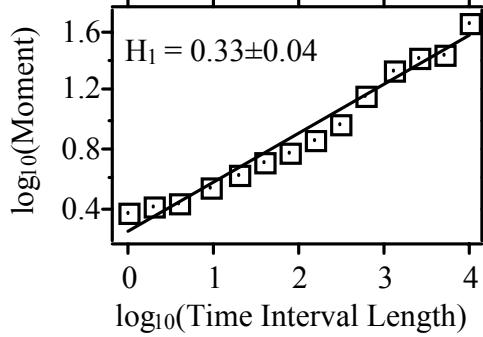
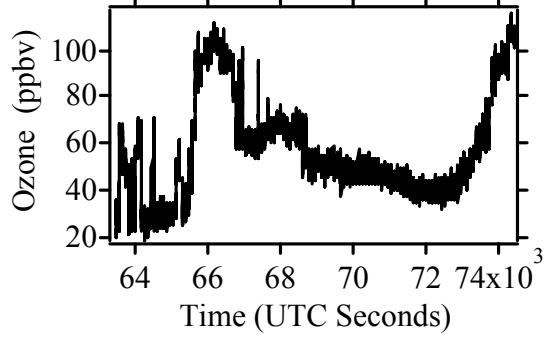
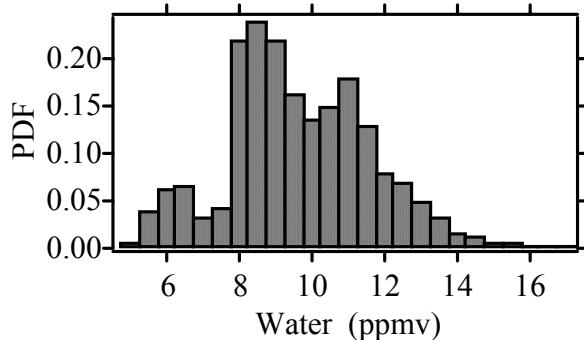
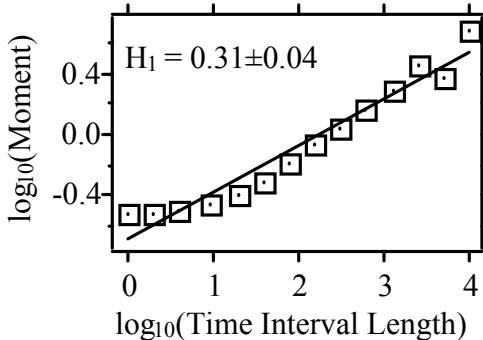
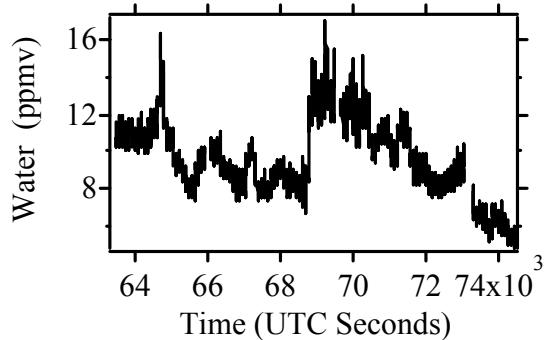
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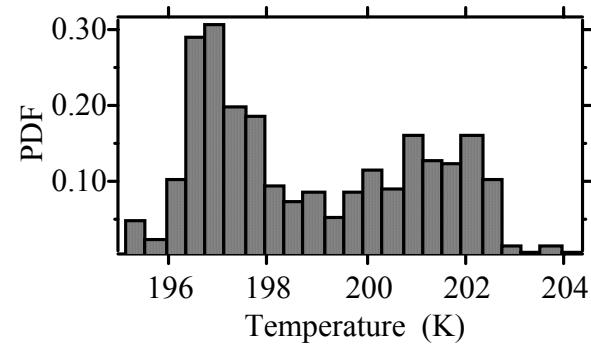
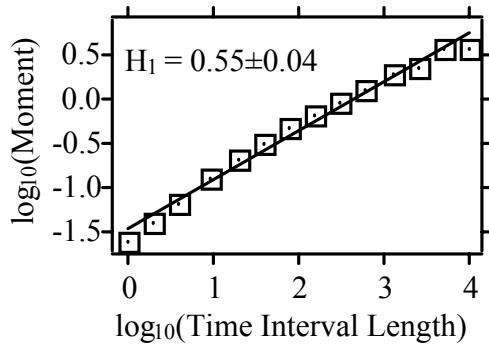
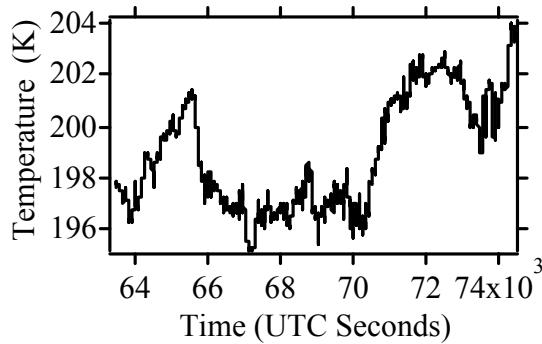
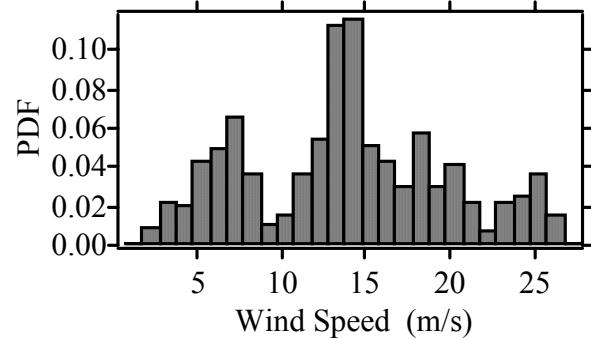
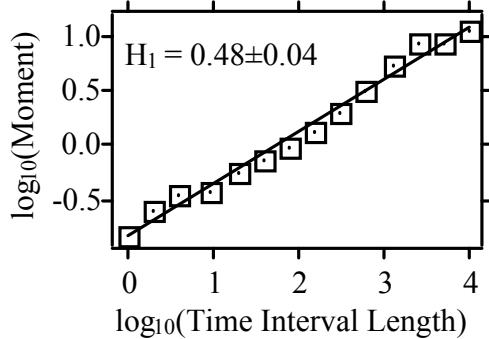
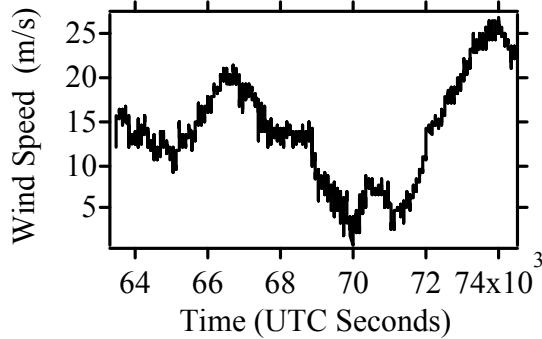
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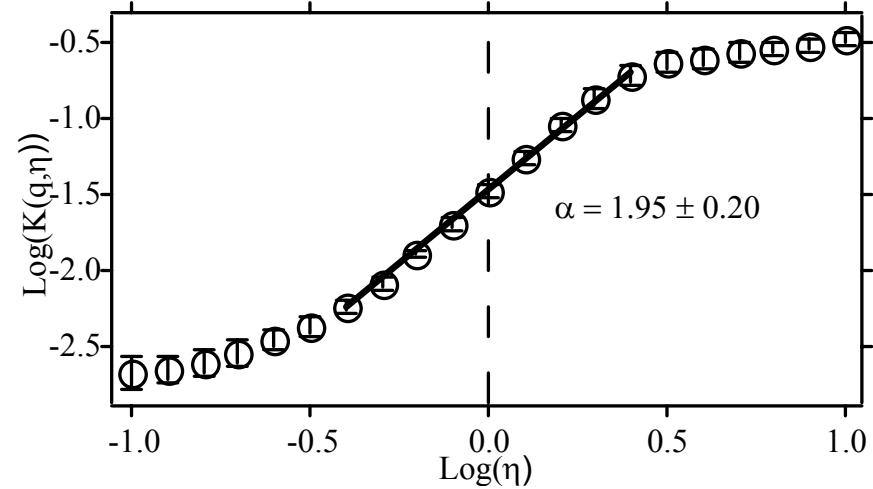
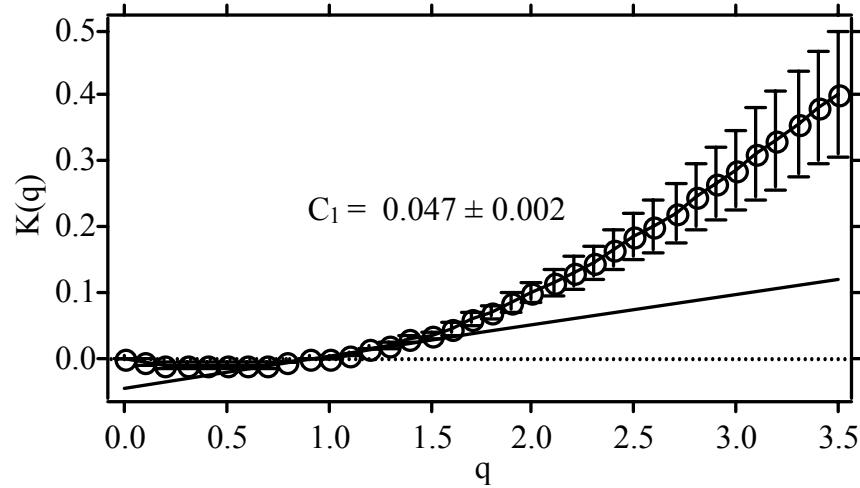
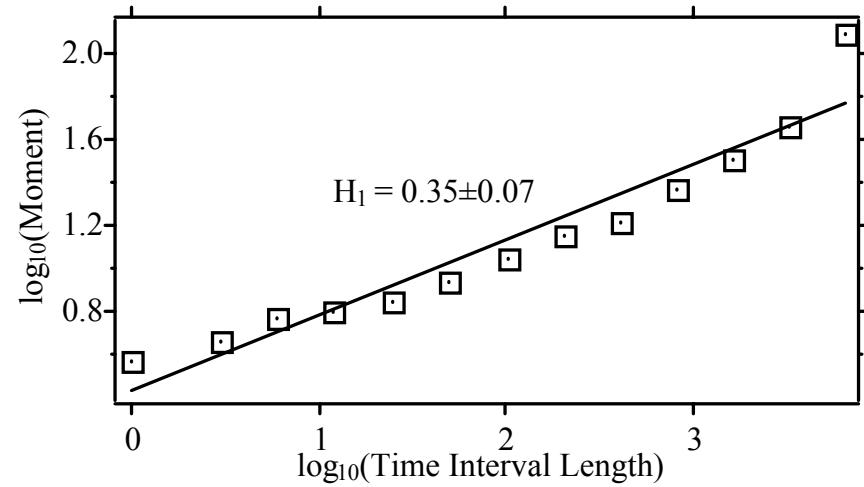
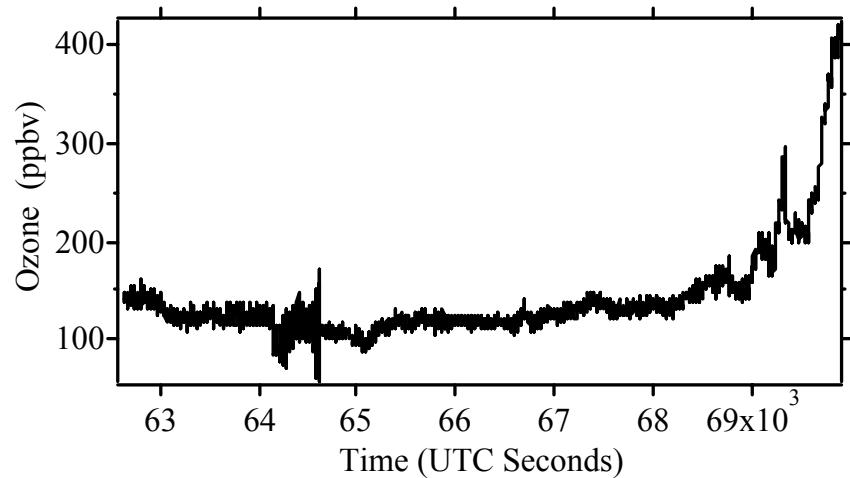
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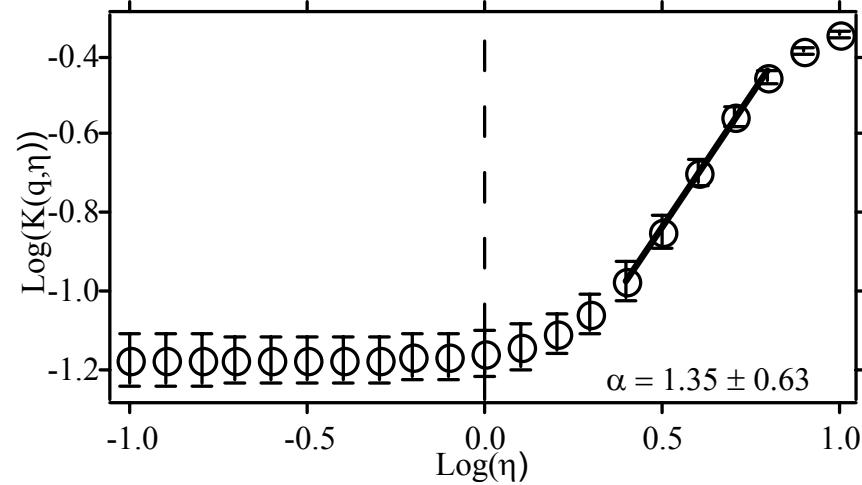
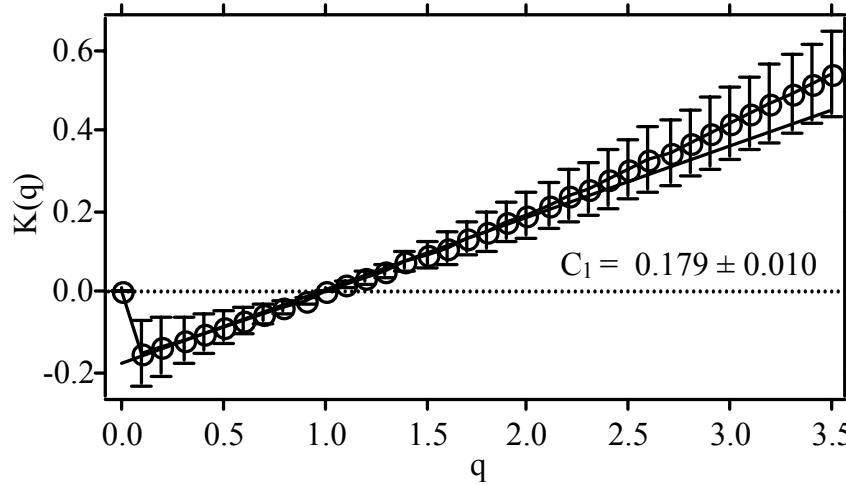
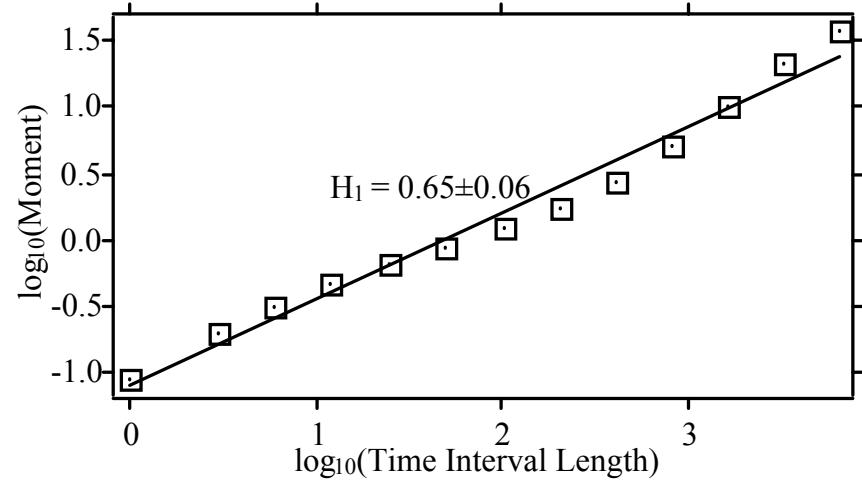
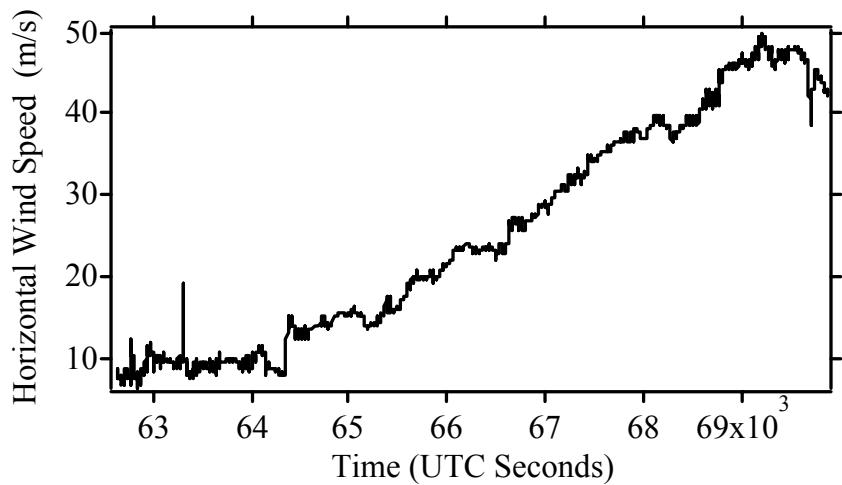
# ACCENT WB57F 19990921 63441-74432



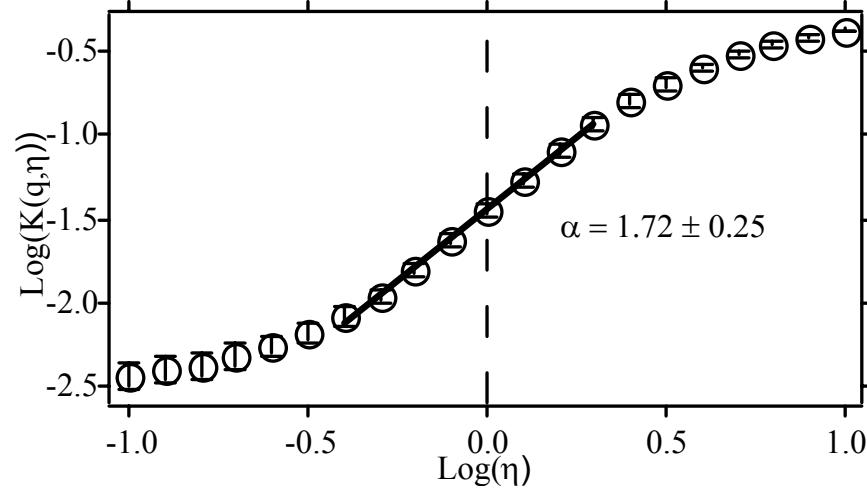
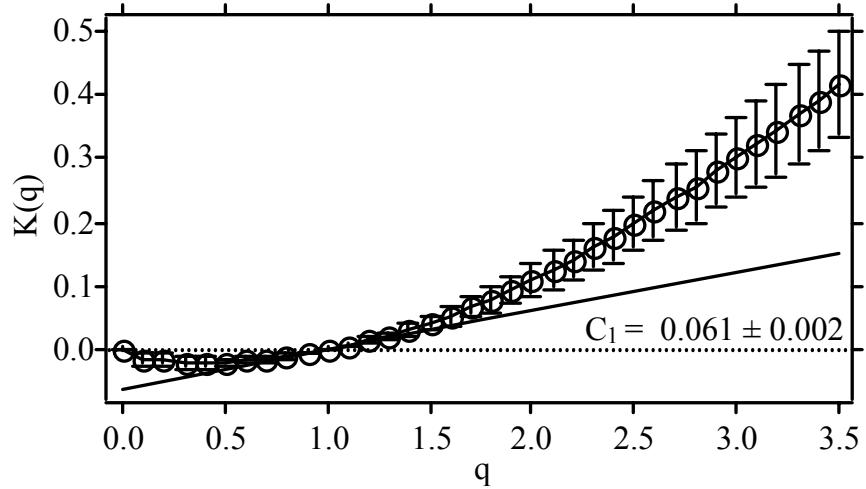
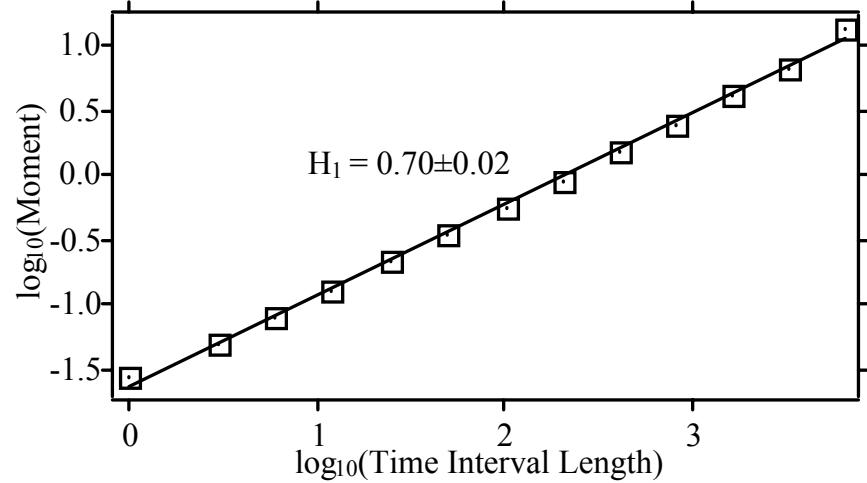
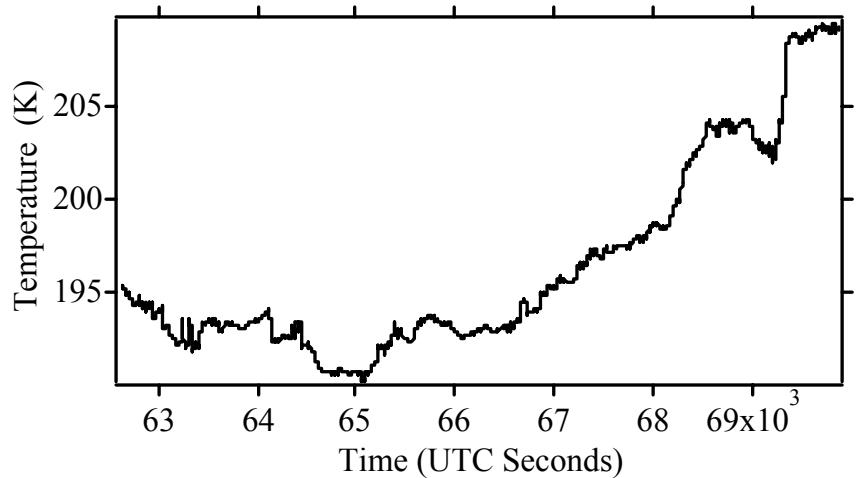
# WAM WB57F 19980501 minlat-begindescent Ozone



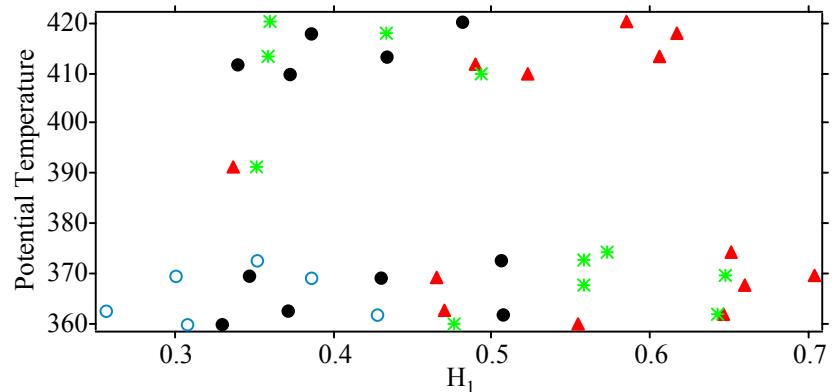
# WAM WB57F 19980501 minlat-begindescent Wind Speed



# WAM WB57F 19980501 minlat-begindescent Temperature

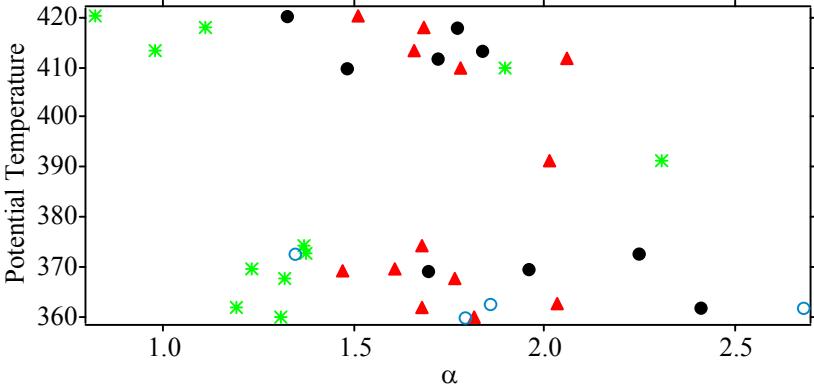
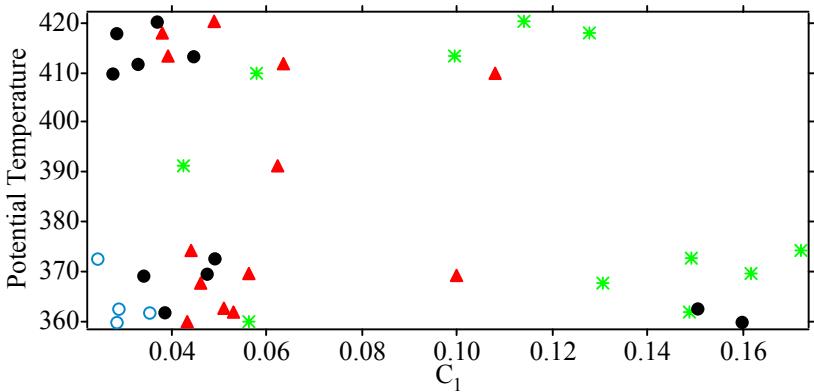


# Scaling Exponents as a Function of Potential Temperature

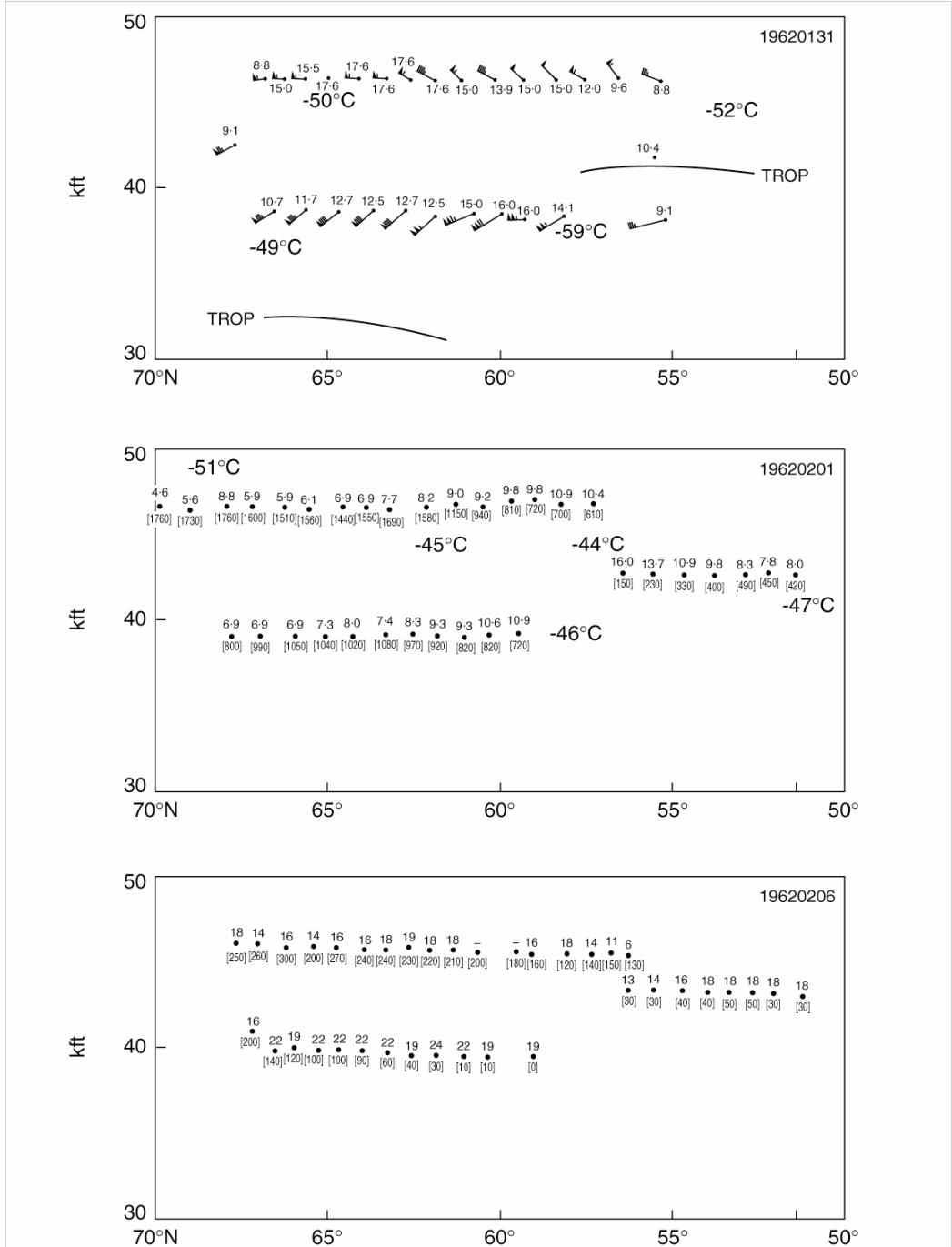


Legend:

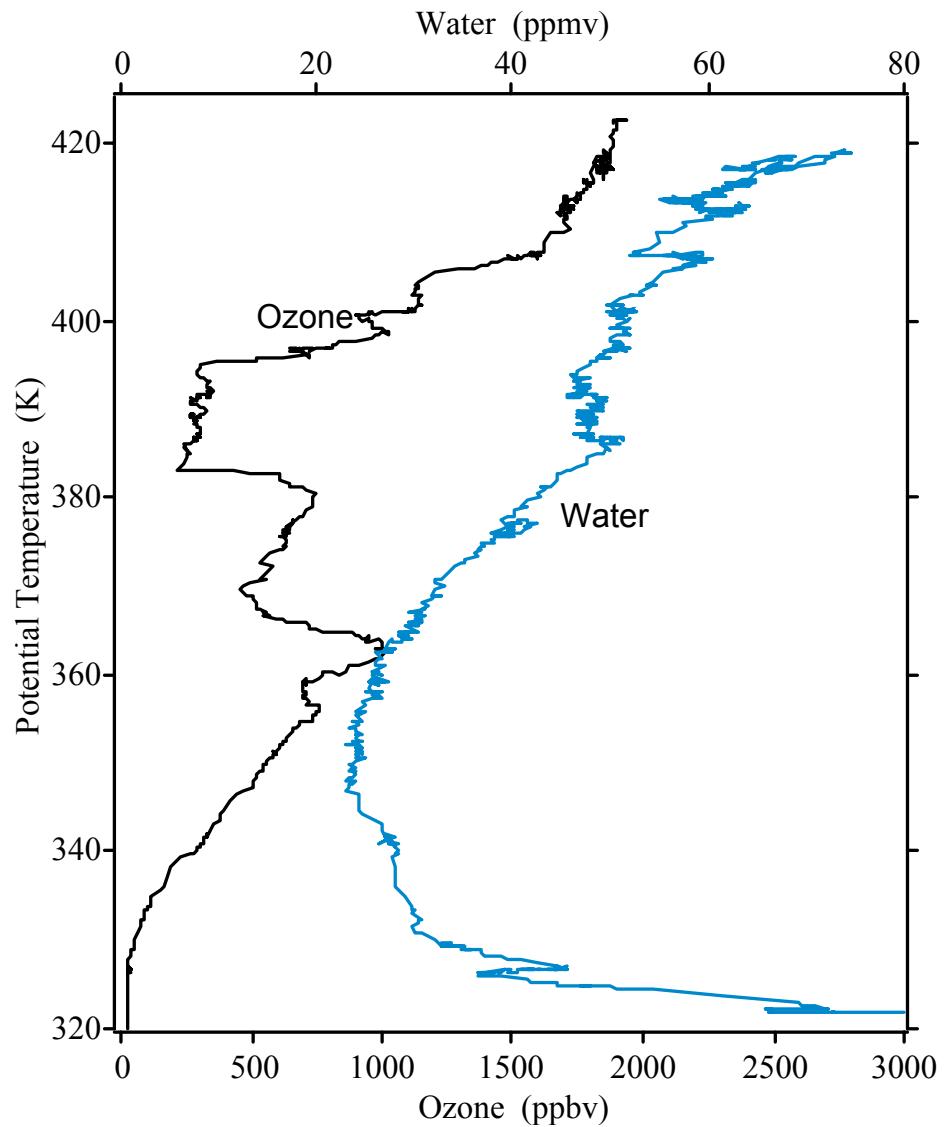
- ▲ temperature
- \* wind speed
- water
- ozone



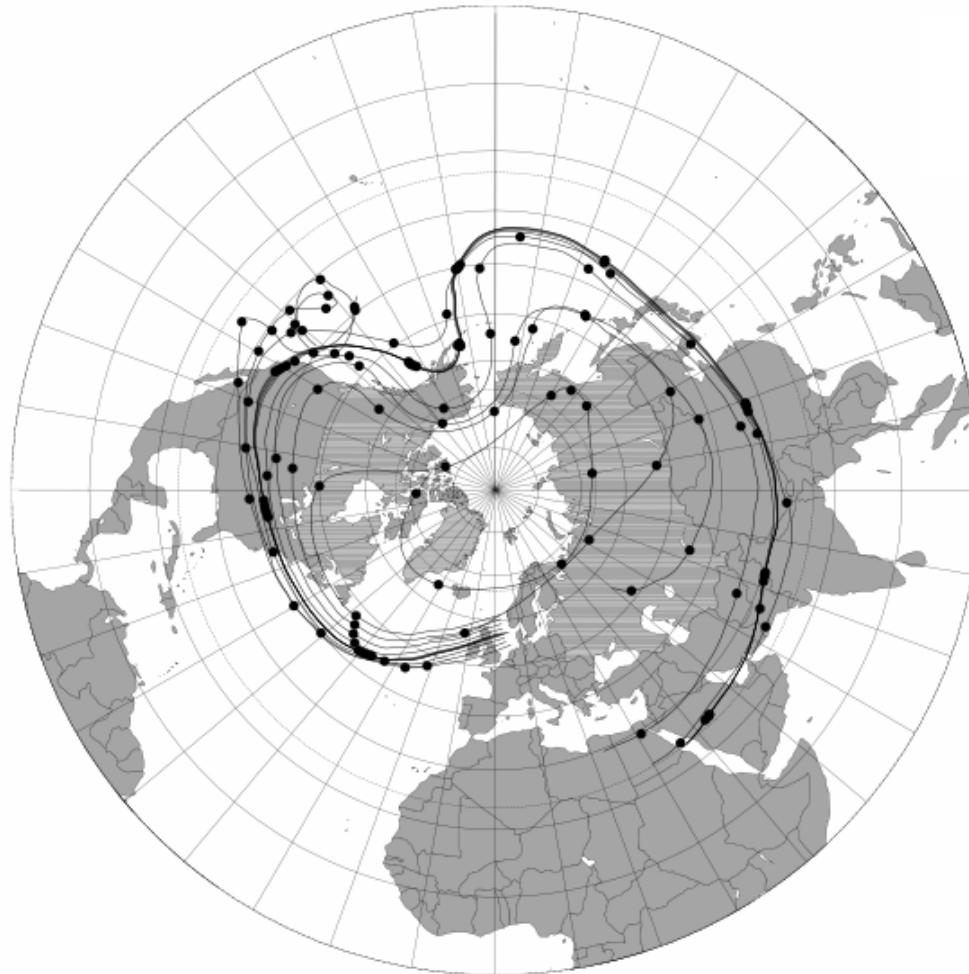
# Water vapor and ozone along the Canberra flight track 55°N-68°N



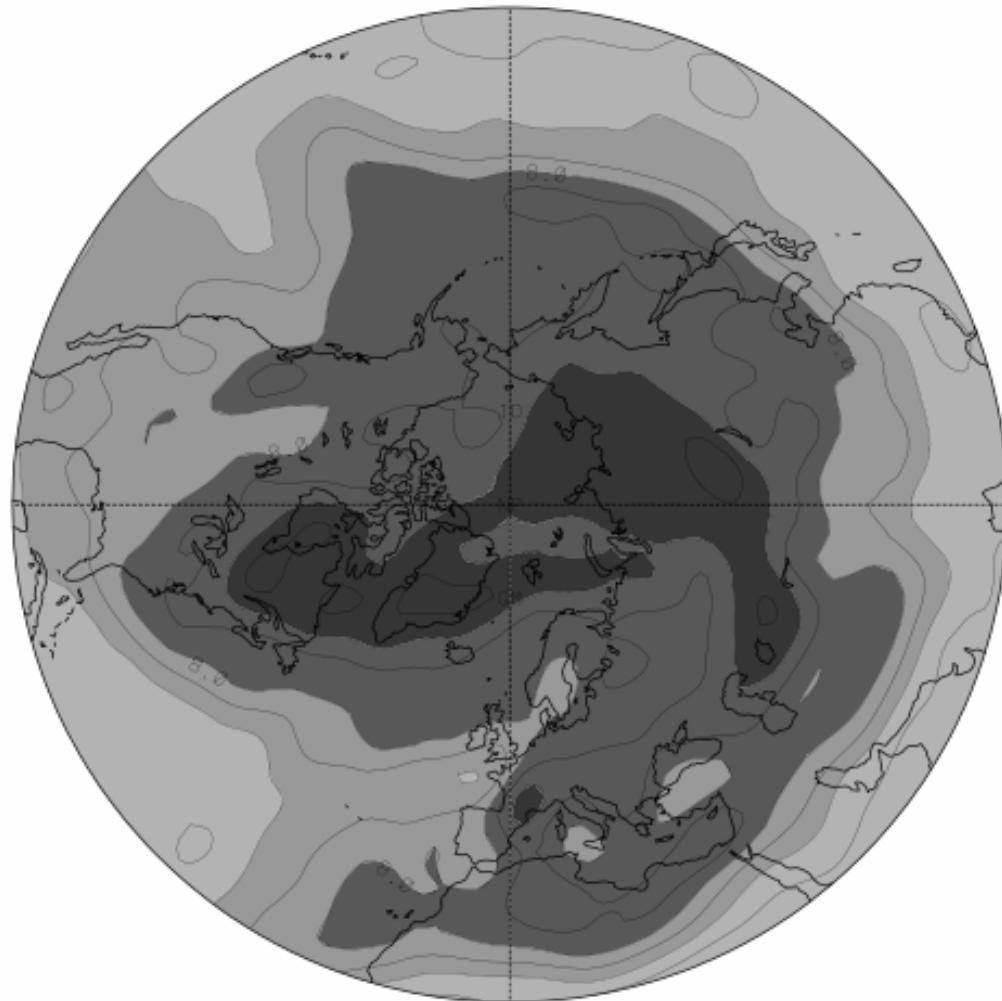
# AASE ER-2 19890207 takeoff-endascent



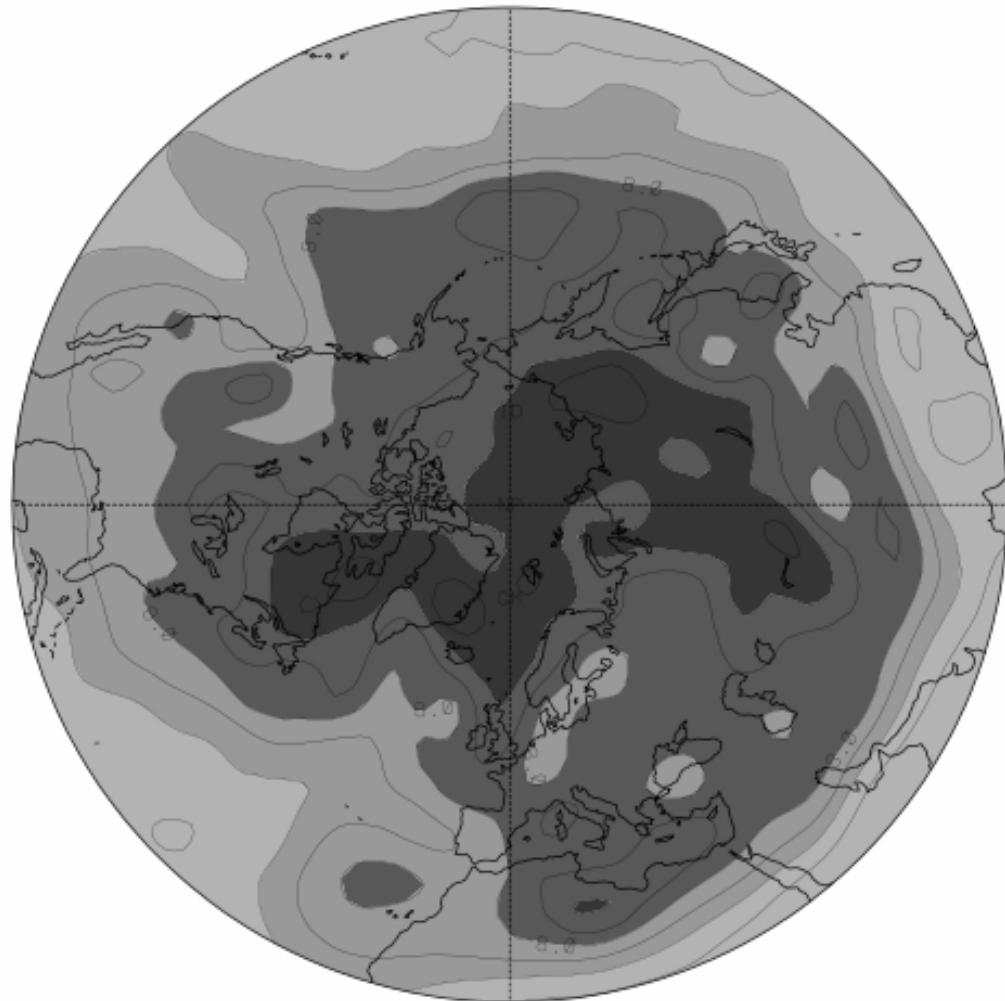
# 19890207 Back Trajectories at 390 K Potential Temperature



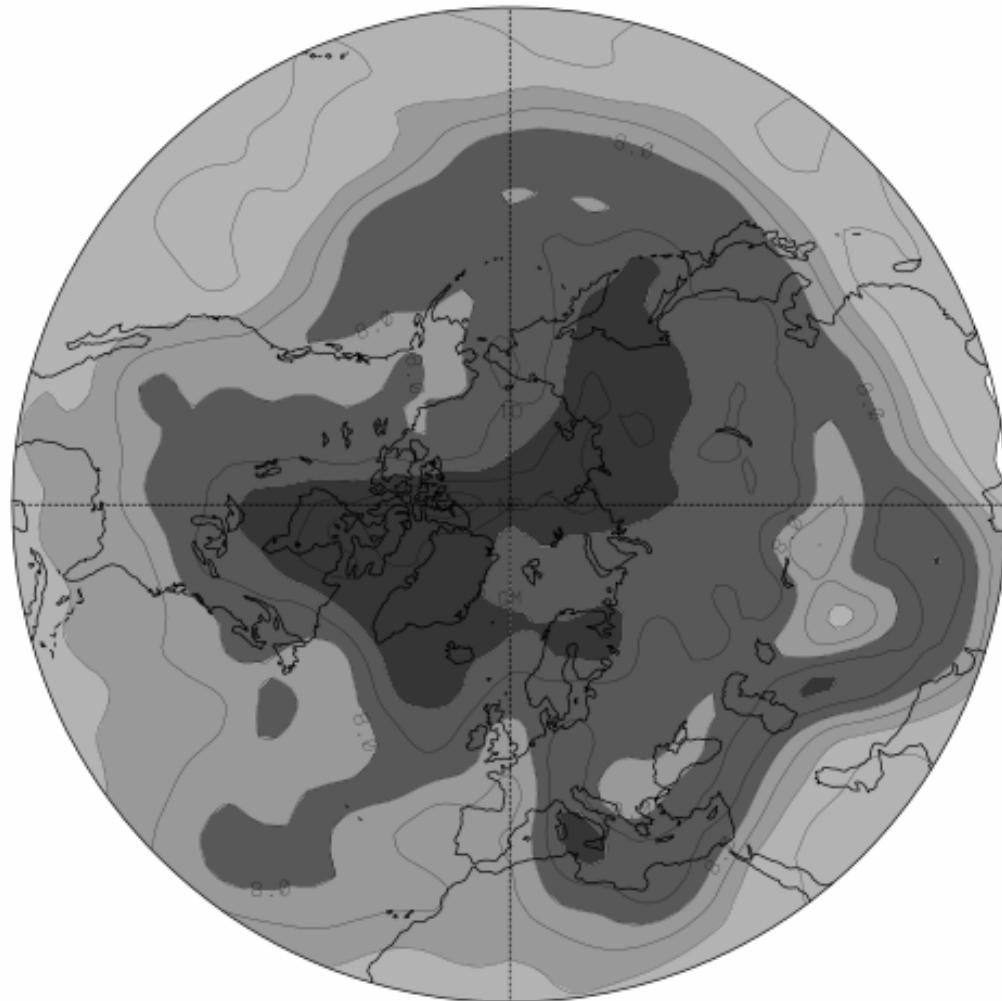
# 19620131 Potential Vorticity, 12 UTC, 375 K



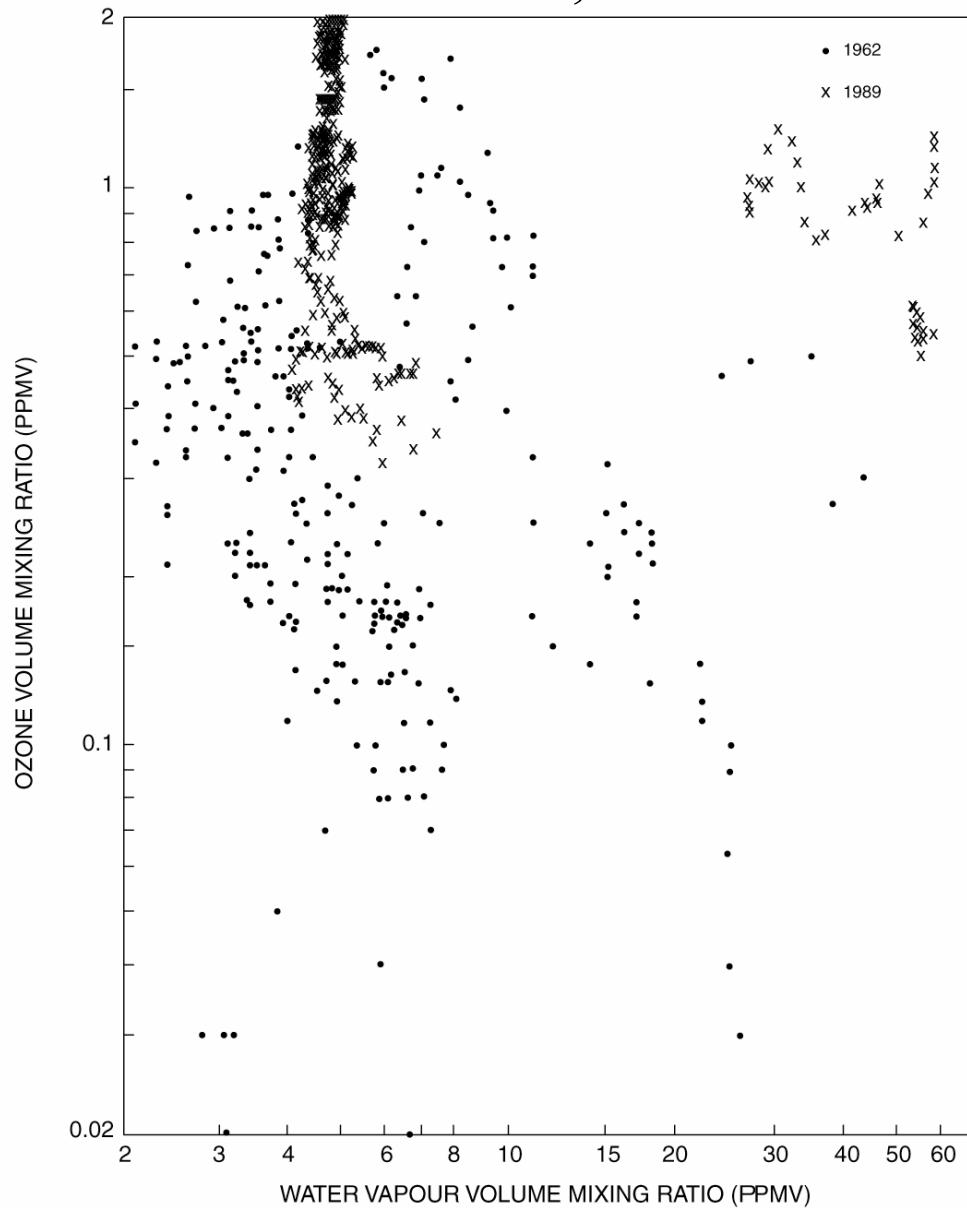
# 19620201 Potential Vorticity, 12 UTC, 375 K



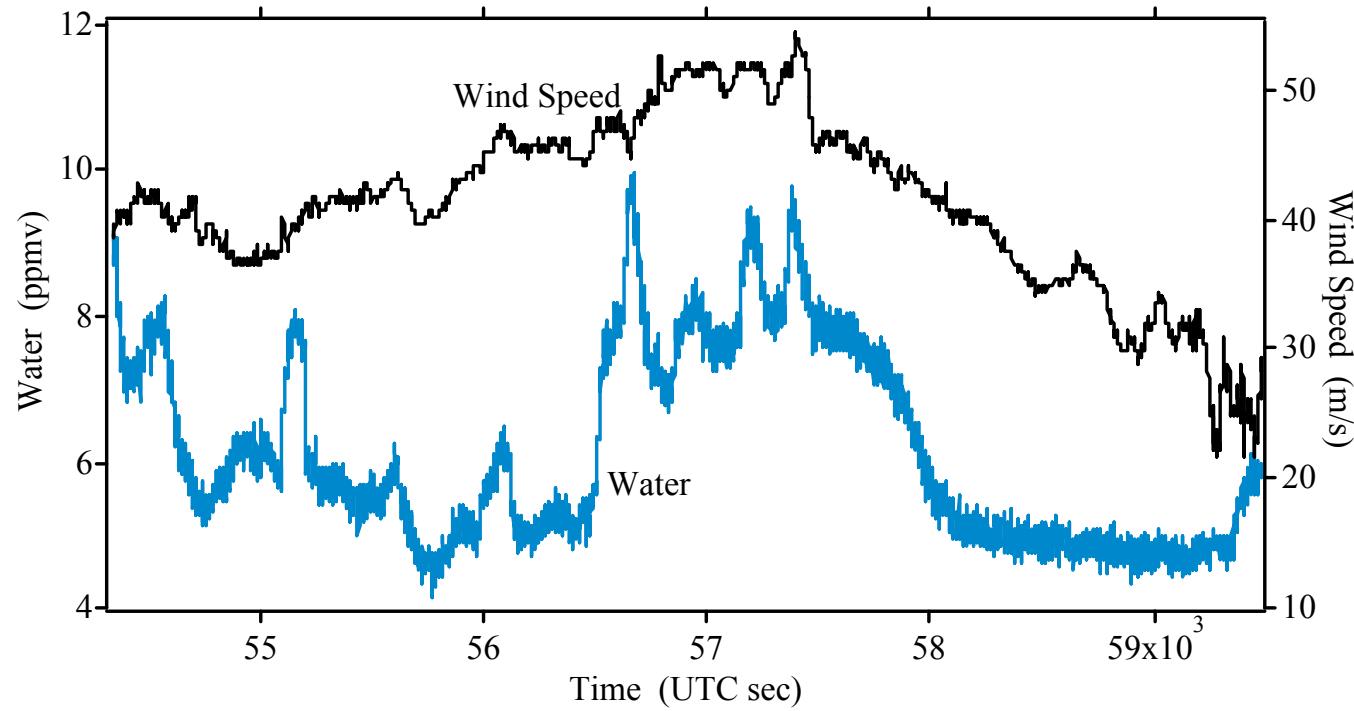
# 19620206 Potential Vorticity, 12 UTC, 375 K



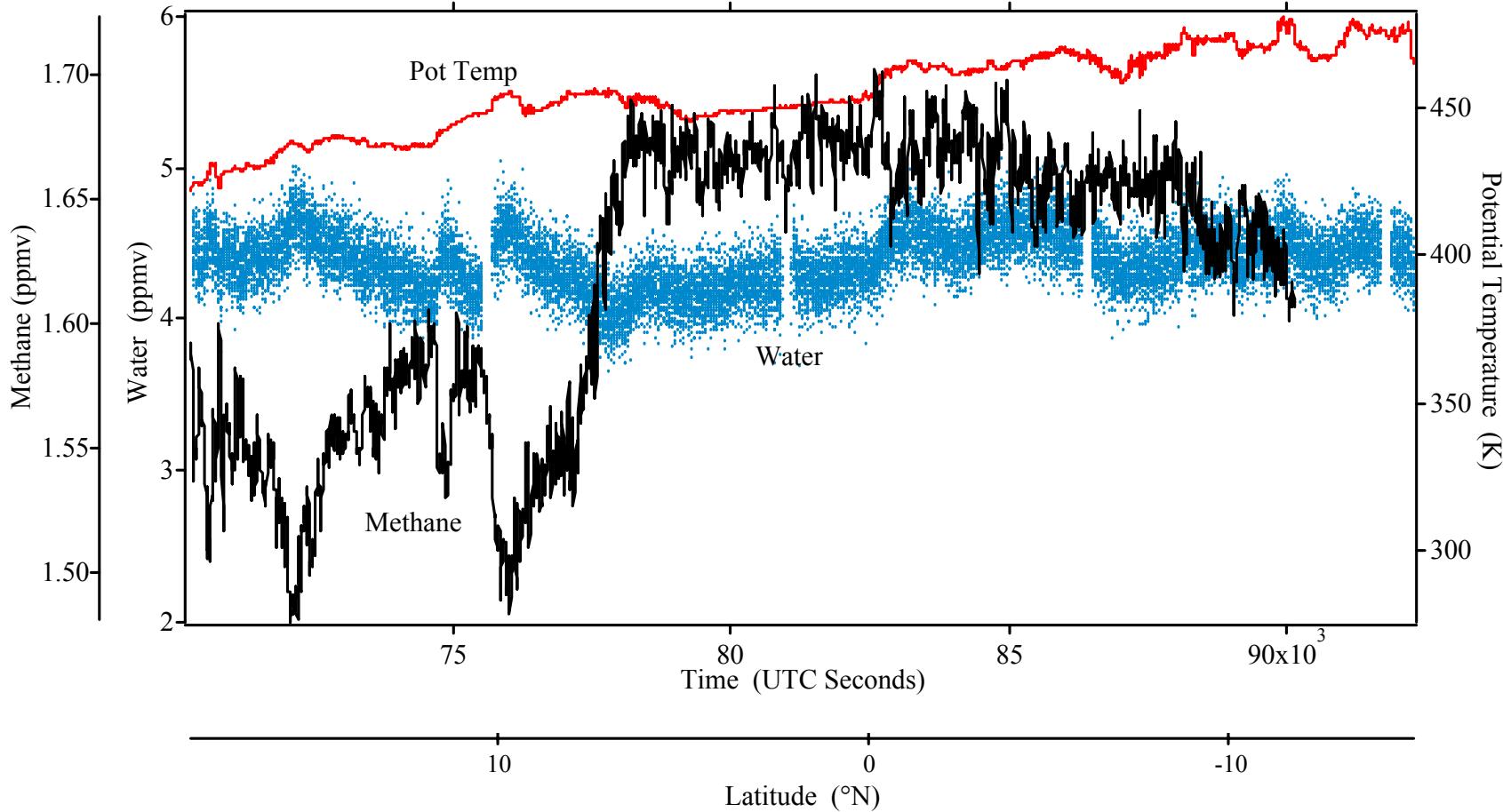
# Ozone vs. Water, 1962 & 1989



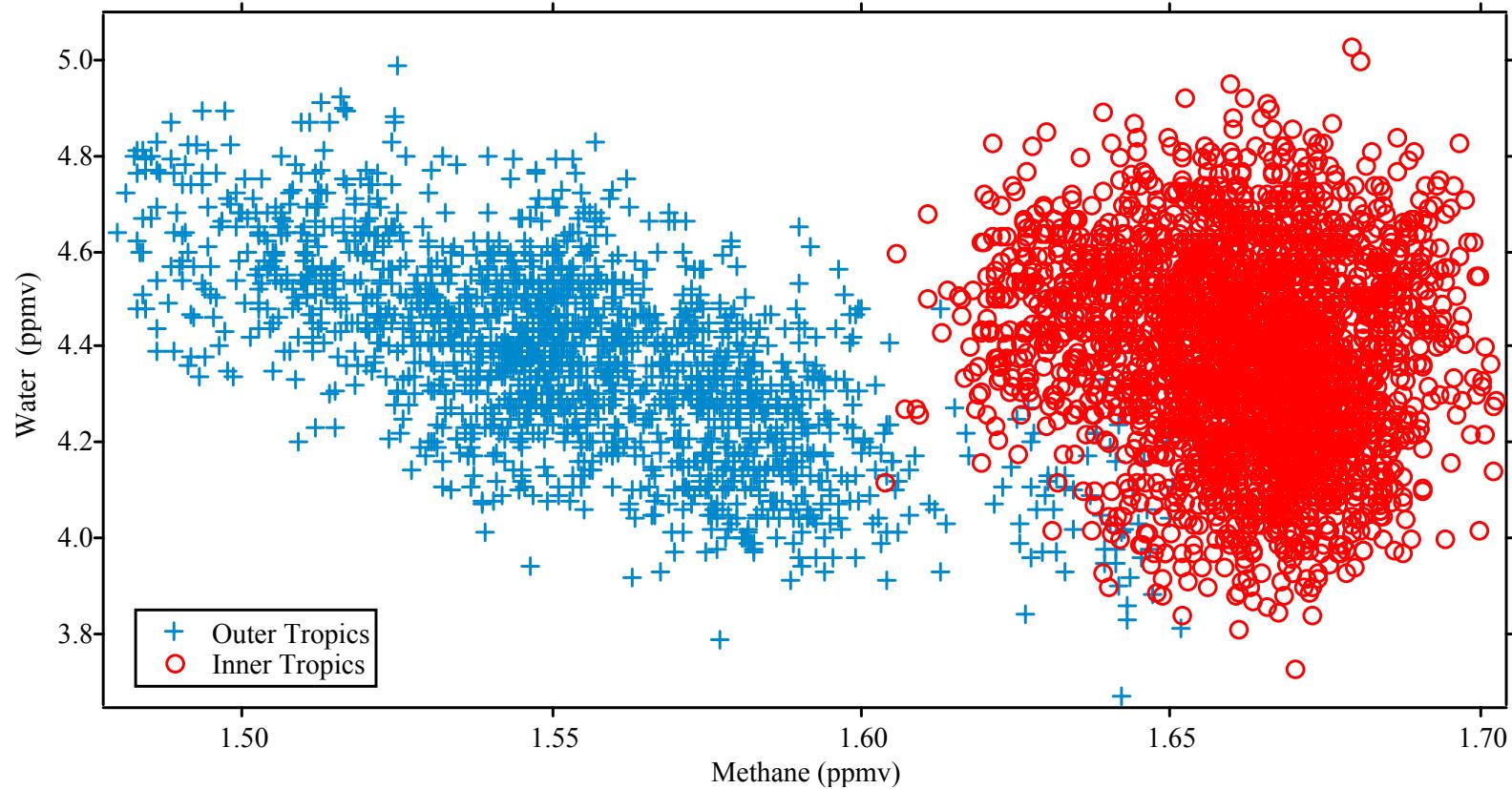
# WAM WB57F 19980507 endascent-beginchgalt, 370 K



# ASHOE ER-2 19940327 Hawaii-Fiji



# ASHOE ER-2 19940327 Hawaii-Fiji



# Scaling Analysis of Airborne Observations Near the Tropopause

Adrian Tuck, Susan Hovde

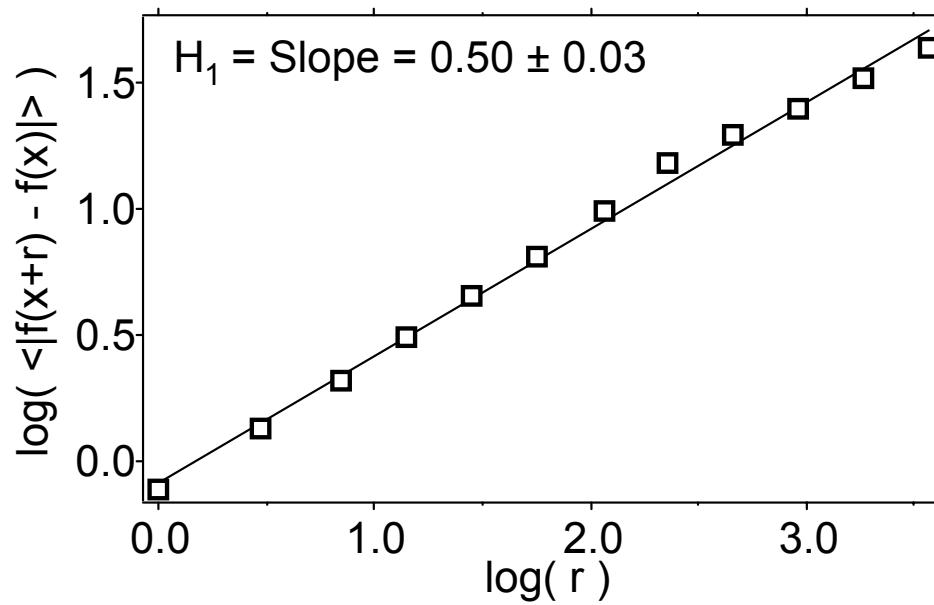
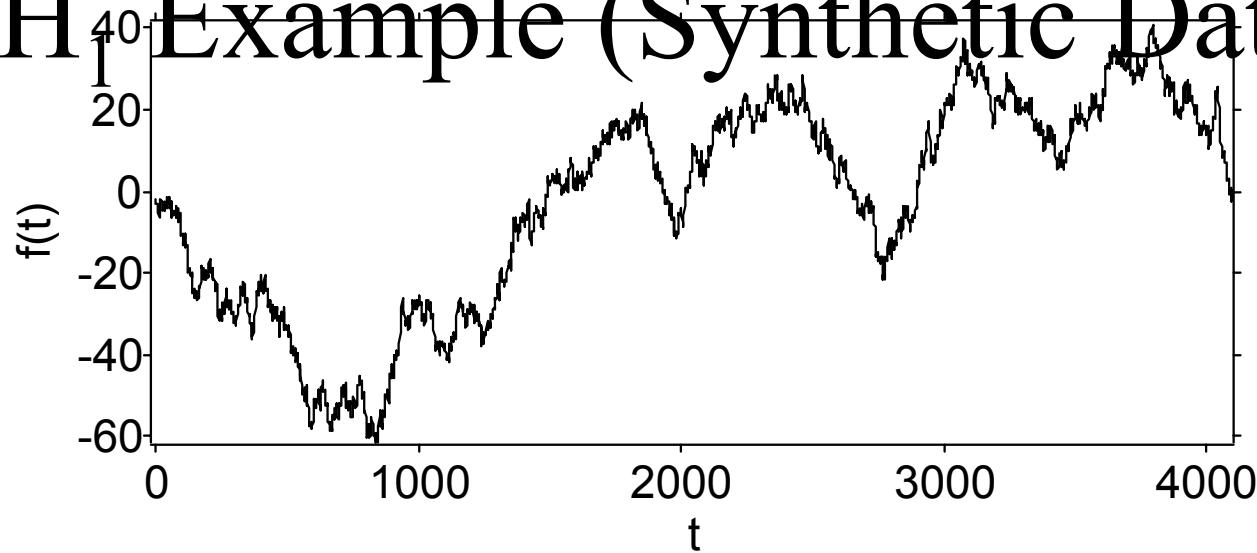
NOAA Aeronomy Laboratory

Shaun Lovejoy

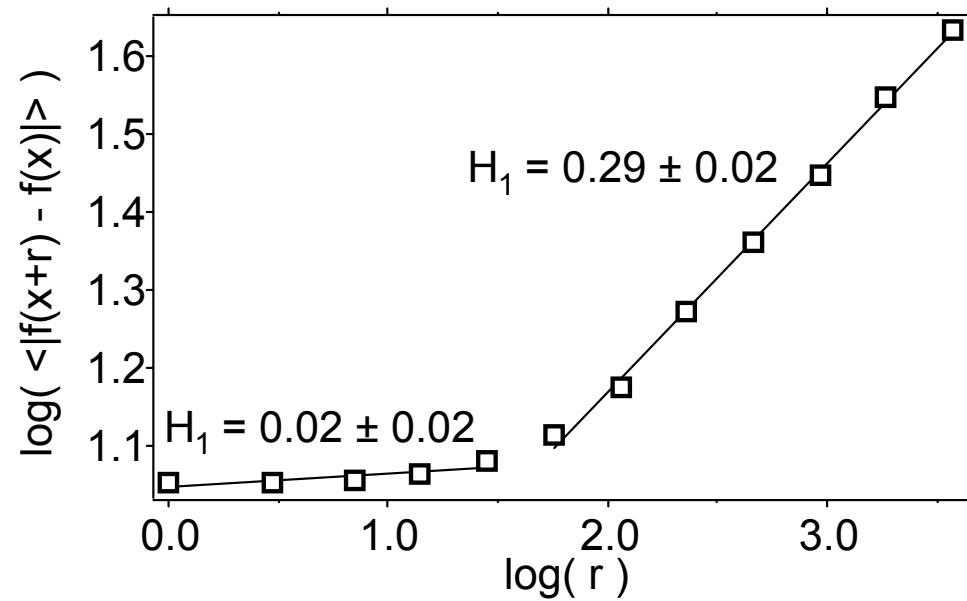
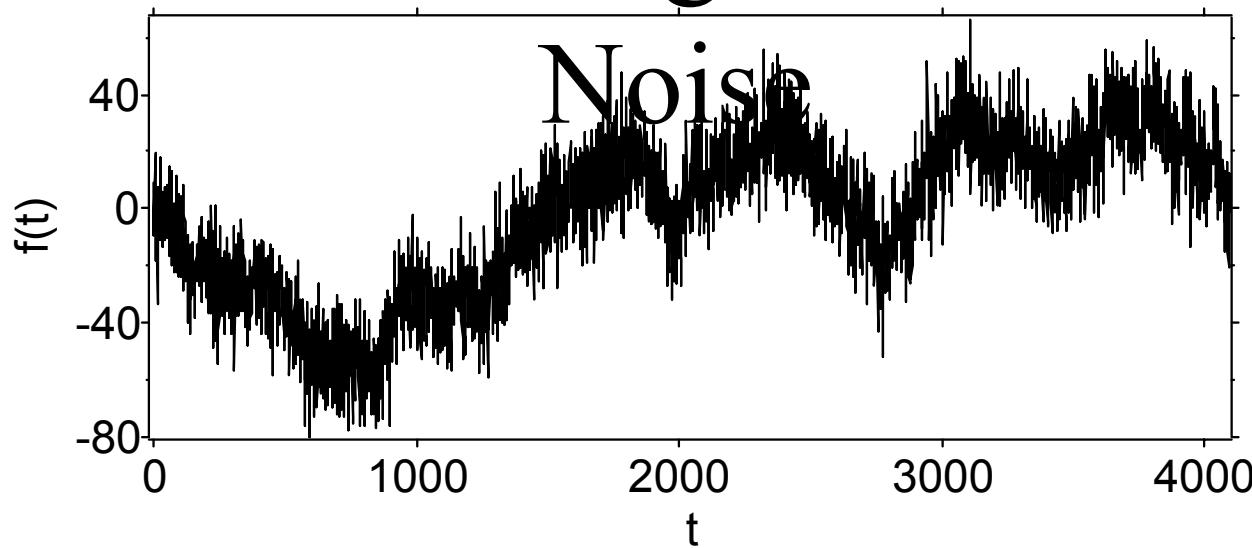
McGill University

Daniel Schertzer

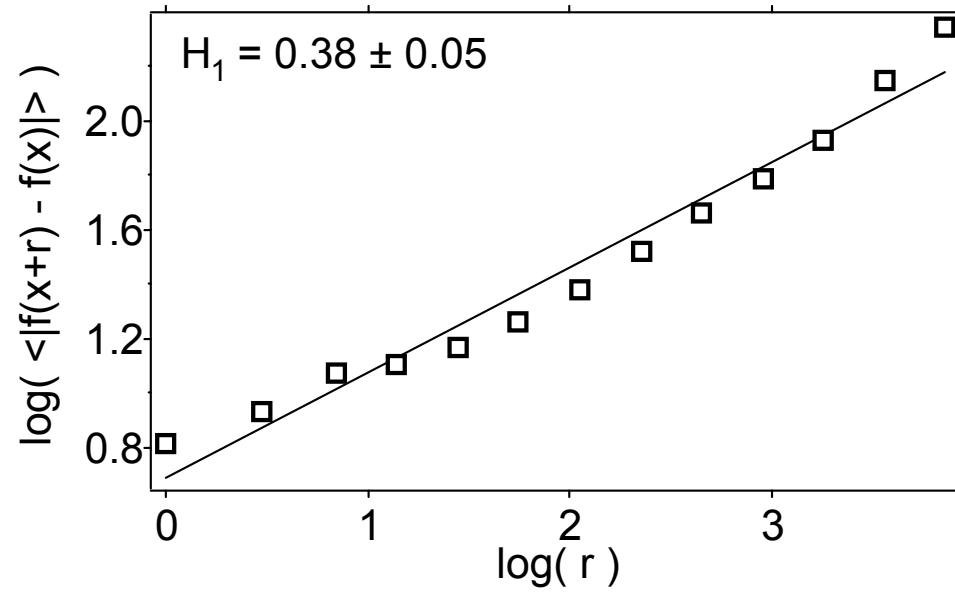
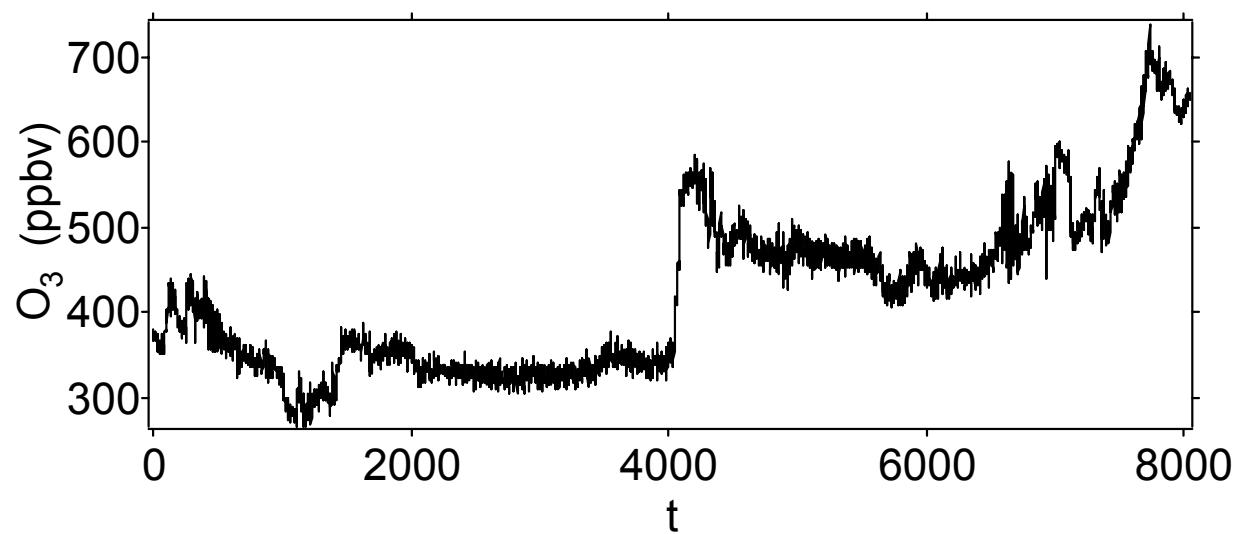
# $H_1$ Example (Synthetic Data)



# Effect of Adding 10% Gaussian



# Stratospheric Segment



# Tropospheric Segment

